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TELECOMMUNICATIONS NETWORKS FOR REMOTE ELECTRICITY

SUPPLY METERING AND LOAD CONTROL

by

PAUL ANTHONY BROWN

B.A. (Hons), C.Eng., M.I.E.E., M.T.M.A.

ELECTRICITY SUPPLY INDUSTRY (UK)

In February 1988 HM Government proposed the privatisation of the Electricity Supply Industry in the UK. As a result pre-1988 titles are referred to in this thesis together with collective and Company titles issued further to the 1988 proposals.

A Thesis submitted to the

OPEN UNIVERSITY

Faculty of Technology

Discipline of Electronics

For the degree of

DOCTOR of PHILOSOPHY

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British Telecom

Central Electricity Generating Board Headquarters

DCP Microdevelopments Ltd

Central Electricity Generating Board, Technology Planning & Research Branch

The Electricity Council Research Centre

Southern Electricity

South Wales Electricity

Isle of Man Electricity Board

Independent Broadcasting Authority

Thorn EMI Dynatel Ltd

ESB Bord Solathair an Leictreachais (Electricity Supply Board, Eire)

Northern Ireland Electricity Service

East Midlands Electricity

Landis & Gyr

Sangamo Weston Schlumberger

States Electricity (States of Guernsey Electricity Board)

South Western Electricity Board

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## ABSTRACT

The aims and objectives of this thesis are to investigate remote electricity supply metering and load control in terms of the now available UK Electricity Supply Industry (ESI) private and national telecommunications networks, the intelligent building, the home computer and domestic energy management concepts.

This work commences with an overview of private telecommunications systems utilised within the U.K. electricity supply industry together with those network services provided by Public Telecommunications Service Operators (PTO's) for customer access (Chapters 1 and 2).

The thesis continues by describing the meter reading and billing processes (Chapter 3) and introduces the concepts of remote metering, the consumer billing interface (Chapters 4 and 5), load control and spot pricing theory (Chapter 6). A review of recent load control and remote metering field trials, conducted in the UK, including feasibility studies are then detailed (Chapter 7). A mathematical analysis of two basic approaches to the principle of 'idle-line' working is also considered (Chapter 7).

The 'intelligent home' concept and the customer billing interface are then considered in conjunction with the development of a 'home computer' applications strategy (Chapter 8). The development of text, communications and control simulation on the BBC microcomputer, are then detailed by reference to the 'Adaptive Microprocessor based System for



Experimentation in the Transmission of Text' (AMTEXT) developed to test the feasibility of the home computer applications strategy developed in Chapter 8 (Chapter 9). The concept of 'idle-time working is then introduced coupled with the concept of 'integration' by way of the national telecommunications network services. Proposals for a Modular Integrated Data Aquisition System (MIDAS) are then considered as a means of illustrating a practical application of both integration and idle-time working (Chapter 10).

The thesis continues by considering network integrity, security and reliability in terms of network architecture and the development of a strategy for quantifying network resilience as a design parameter (Chapter 11).

Finally, the thesis concludes by summarising the work undertaken and the results obtained with respect to the initial objectives, and details potential areas for further research.

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## CHAPTER 1

### TELECOMMUNICATIONS SYSTEMS AND NETWORKS WITHIN THE ESI

#### 1.1

##### Historical Background

For almost a century, the domestic consumption of electrical energy has been metered by the electromechanical watt hour meter. Conceived by Ferraris in 1884 this meter has not changed in its method of operation since that time. (331) Its manufacture in immense quantities, worldwide, has led to a great deal of innovation in detail design and in simplicity of assembly and calibration. Today it is a mature product, offering excellent performance for its cost.

Attempts to promote the remote metering concept have been made for well over a century and the patent literature provides a testimony of the wide range of work that has been carried out. Perhaps the first proposal was made by (328) Edward Davy, who suggested using the communications network to monitor the voltage of batteries at the unmanned repeater stations for the London to Liverpool telegraph system in 1838. The reliability of the batteries was always suspect and remote monitoring of their voltages was important in order to prevent failure of the system. Davy's work was recognised and he was (329) granted a patent in the countries of England and Wales and the town of Berwick on Tweed.

In 1902 Chester Thordason of Chicago devised his system for the remote (92) reading of electricity meters. His proposals for implementation included the use of signal wire. There was insufficient cost justification and the system was discontinued. In 1913, automatic electromechanical meter repeaters were produced, and in 1927 a system was patented which utilised thermionic valves. This system in fact utilised over 29 thermionic valves and 30 filament batteries. Needless to say this solution could never be cost justified, was unreliable and much too large.

Between 1936 and 1947 further advances in electronics technology such as the indirectly heated cathode and the miniature valve reduced the size of equipment. In the 1950's and 60's the transistor and integrated circuit reduced equipment size and power consumption still further and by 1980 the microprocessor was appearing in proposals all over the world.

If the development of the remote, electronic, meter poses a problem, so does communicating with such a device and load control or supply demand management adds further to the dimension of the problem.

(312)  
One of the basic aims of Demand Management Schemes is to shift the use of electrical energy from peak periods to off-peak periods and thus match generating capacity to load requirement. At present the generating utilities in the UK (Nuclear Electric, National Power and Power Gen)\* predict the demand for electrical energy and provide sufficient generation to meet the peak demands.

The practical implication of a Demand Management Scheme in the UK requires a telecommunications infrastructure which encompasses the generating, transmission and distribution utilities (Nuclear Electric, National Power, Scottish Hydro Power, Scottish Power, National Grid Co, and the 12 Regional Electricity Companies) and the consumers whose load would be liable for control.

(98)(312)  
In the UK, Demand Management is implemented with some very large customers but little, if any, control exist on the demand of the vast majority of consumers. Peaks occur for only short durations and are costly overheads for the utilities. However, if load control was exercised by the supplier on the average consumer a more even distribution of the daily demand for electrical energy could be achieved.

\* to include Scottish Hydro and Scottish Power

A prime requirement for both remote metering and load control is a telecommunications infrastructure capable of providing the information transfer system to support the communications required, at all levels, between the Utilities and their customers both large and small.

This the is aims to investigate remote electricity metering and load control in terms of the now available UK ESI (Electricity Supply Industry) and national telecommunications networks and systems, the intelligent building, the home computer and domestic energy management concepts.

### 1.1.1

#### Introduction

A good, reliable and rapid telecommunications service is essential to all large organisations. This is particularly so in the ESI as its basic commodity - electricity - can not be stored. The demand for electricity fluctuates continuously and has daily and seasonal peaks. Supply must be matched simultaneously to this fluctuating demand. Under normal conditions telecommunications facilities assist in minimising production costs whilst at the same time ensuring the maximum security of supply.<sup>(121)</sup> Electric energy has been called the life's blood of an industrialised society and it is a useful analogy. When a power system fails most productive work stops in the area affected. The longer the outage the more costly the interruption becomes to society.

### 1.2

#### Requirements for ESI Telecommunications Networks

There are a number of important parameters for telecommunications networks utilised within the ESI.<sup>(125)</sup> Examples of these are as follows:-

#### 1.2.1

##### High Reliability

This necessitates the minimisation of loss of communications, and of undetected data bit errors, even in the event of adverse noise conditions and high rises of local earth potential.

1.2.2High Availability

The system should suffer only minimum degradation in the event of circuits failing due to shortcomings of the hardware or software.

1.2.3Rapid Response

A real time response is essential, especially in teleprotection signalling.

1.2.4Economy

The required performance has to be achieved in an economical manner.

1.2.5Flexibility

The many changes required as the power network parameters alter, make it desirable that the telecommunications network should itself be capable of being readily and easily changed to embrace new geographic locations. Apart from ease of provision this implies a need for having inherent spare bandwidth capacity to facilitate the accommodation of new services and for new locations. Standardization and upwards-compatibility should be included.

1.2.6International Comparisons

Table ( T11 ) shows some statistics published by CIGRE (Conference Internationale Des Grands Riseaux Electriques a Haute Tension) for 1980.

Comparison between telecommunication circuits used in different countries 1980

Country	Audio Cables	PLC	Radio Links	Rented PTT
Austria	660	1,587	771	394
Germany (FED)	85,000	3,000	9,000	1,400
Belgium	977	26	385	199
Denmark	146	426	30	356
Gt. Britain (CEGB only)	390	30	30	1,830
Ireland	85	175	120	47
Italy (ENEL only)	1,300	6,834	2,430	70
Japan	12,012	1,101	5,581	41
Switzerland	180	1,440	320	40

Table T1.1

1.3Area Board Trunk Networks1.3.1Introduction

Trunk networks provide the main telecommunications highways between the major Commercial, Engineering and Administrative centres (or Nodes) within an Area Board. This includes Board HQ, Computer Centre(s), Area Offices, Zone Offices and Depots, Customer Service and Accounts Bureaux, Engineering Control and Customer Reporting Centres, Showrooms and Substations.

The trunk networks provide communications for a wide variety of telecommunications systems such as telephony, radiotelephony, telecontrol, remote mainframe computer terminals, text transmission etc. It is worth noting that in order to fully appreciate many of the existing trunk network configurations reference should be made to the constantly changing communication requirements within an Area Board together with the means of communication between customers and staff (distributed from their central database(s)) and the requirement for the rapid accurate and cost effective transfer of information.

With reference to future systems and in particular the almost endless possibilities that can be foreseen in the field of network communications it is very easy to get carried away and forget the reasons for having such facilities. These are simply to help make the power distribution system and associated customer services more efficient and reliable, thus giving a better standard of service, at minimum cost, to the consumer. Unless any refinement to such networks does this it cannot be regarded as a requirement but as a luxury. Any such refinement must be subjected to a cost benefit analysis before it can be incorporated in the network or even result in a minor network reconfiguration. However in conducting such an exercise due weight should be given to both the potential short and long term penalties to be paid for the exclusion or omission of such refinements. Uneconomic schemes may require to



be installed or applied to the network on a prototype basis but even these schemes can be properly assessed if we ensure that we obtain as much value as possible in the form of experience.

### 1.3.2

#### Trunk Network Fundamentals

The elements of all telecommunications are encompassed within four areas:

TERMINALS

TRANSMISSION

SWITCHING AND CONTROL

SIGNALLING

During the 1960s there had been a growing realisation of the importance of considering telecommunications networks as integrated systems. The traditional independent development of switching and transmission was considered by experts to have prevented the evolution of optimum engineered telecommunication systems.

### 1.3.3

#### Frequency Division Multiplexing (F.D.M.)

Early trunk networks provided for the transmission of multichannel telephony, telegraphy and facsimile over relatively short distances by cable and nationally by microwave links. The basic transmission module consisted of 12 circuits obtained by applying F.D.M. techniques. To produce a channel the audio frequency speech is used to modulate a highly stable carrier frequency to produce 4 kHz bands adjacent to each other in blocks. For systems up to 960 channels capacity, the standard blocks are a group (12 speech channels between 60 and 108 kHz) and a supergroup (60 speech channels of five groups between 312 and 552 kHz). These groups/supergroups are then interleaved to fully utilise the whole available spectrum of the bearer circuit, i.e. microwave channel or coaxial cable. The channel/group/supergroup configurations are illustrated in Fig.(11).

6

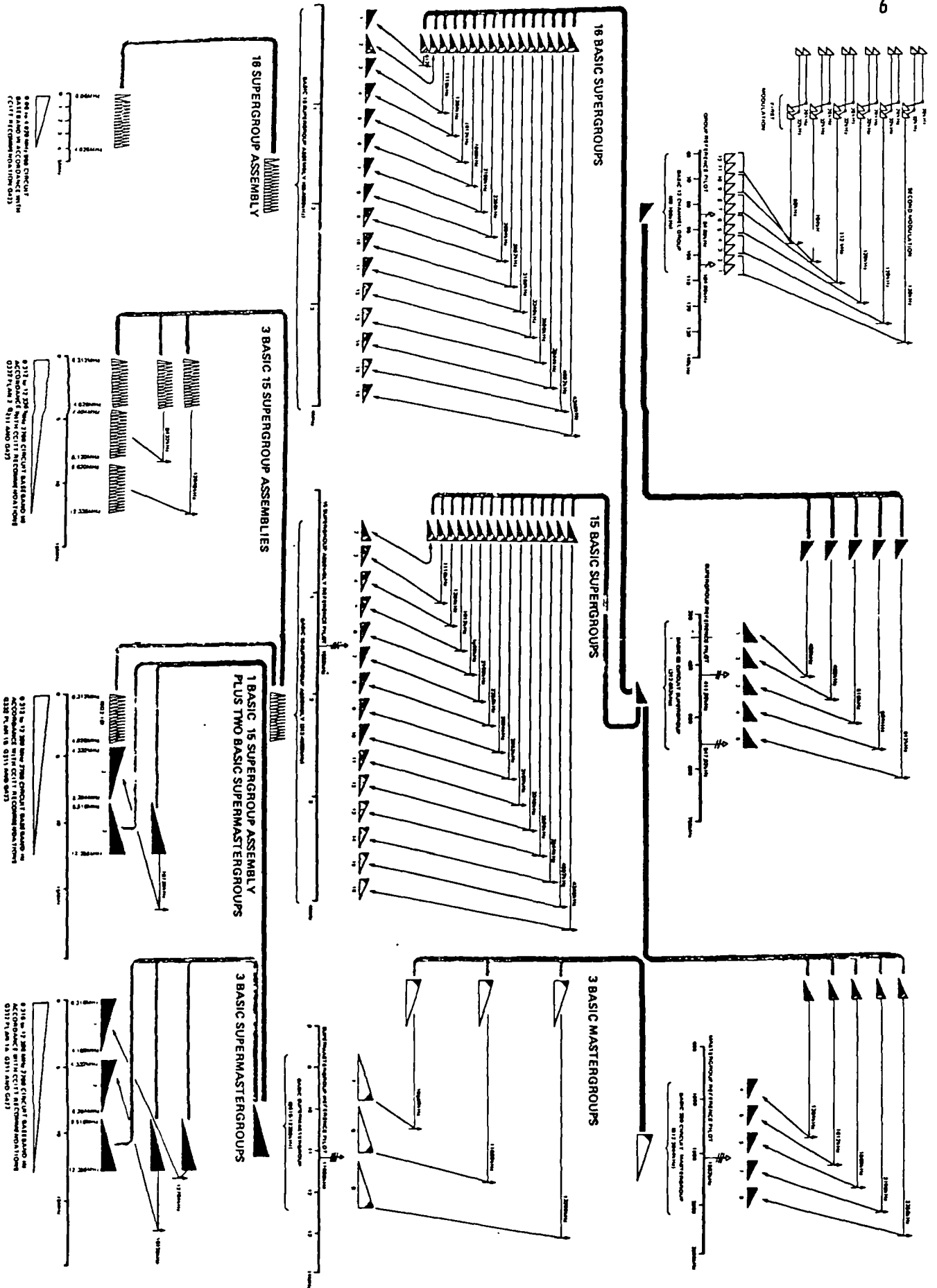


Fig 1.1 FREQUENCY DIVISION MULTIPLEXING

1.3.4Time Division Multiplexing (T.D.M.)

In the early 1960s a new technique of multiplexing became economically viable for trunk networks providing 24 channels of speech over the 10 to 20 mile range on deloaded twisted pair cables. This technique known as Pulse Code Modulation (P.C.M.) involves the sampling of each speech channel in turn at a rate of 8000 times per second, which is high enough to represent speech frequencies. The samples are combined or interleaved together to form a time division multiplex signal. Then the volume range of these amplitude modulated pulses is divided or quantised into 128 logarithmically spaced levels which are each represented by a binary code of seven digits or pulses, producing the P.C.M. signal. The composite signal to line is 1.536M bit/sec for 24 ch. systems and 2.048 Mbit/sec. for 30 (32) Ch. systems.

Quantisation noise is the main impairment of the signal when transmitted by P.C.M. and is due to the difference in actual signal amplitude and the level which is coded to represent it. The levels are logarithmically spaced so that they are closer together at small amplitudes; this improves the signal/quantisation noise ratio at these amplitudes. Linear spacing would require many more levels (about 2000) for the satisfactory reproduction of speech. This would lead to a binary code of 11 digits for transmission, and have the disadvantage of greater coder complexity and more line bandwidth.

Regenerative repeaters are installed in underground repeater boxes spaced at 2000 - yard intervals, generally sited in manholes, pillars or cubicles. These repeaters equalise the line to give good pulse transmission, amplify the pulses, then retime and reshape them. Power feed to the repeaters is via the cable pair phantoms.

Synchronisation of the receive terminal with the transmit terminal is necessary to locate the time position of the channels in the pulse stream. Information for this together with channel signalling is contained in 'spare' digits.

The essential elements of a P.C.M. system are shown in Fig. (12) including the basic regenerator components. Initially P.C.M. systems were 24 channel but the majority of line based systems are now 30 channel and 120 channel systems are utilised on optical fibre and microwave radio bearers and are illustrated in schematic form in Fig. (13).

### 1.3.5

#### Digital Techniques

With the availability of digital transmission techniques (P.C.M. systems etc) which lend themselves to the application of large-scale integration, at low cost, the drive to fully integrate transmission and switching on future trunk networks has gained tremendous momentum. Digital techniques offer significant service and economic advantages to networks in a number of ways:-

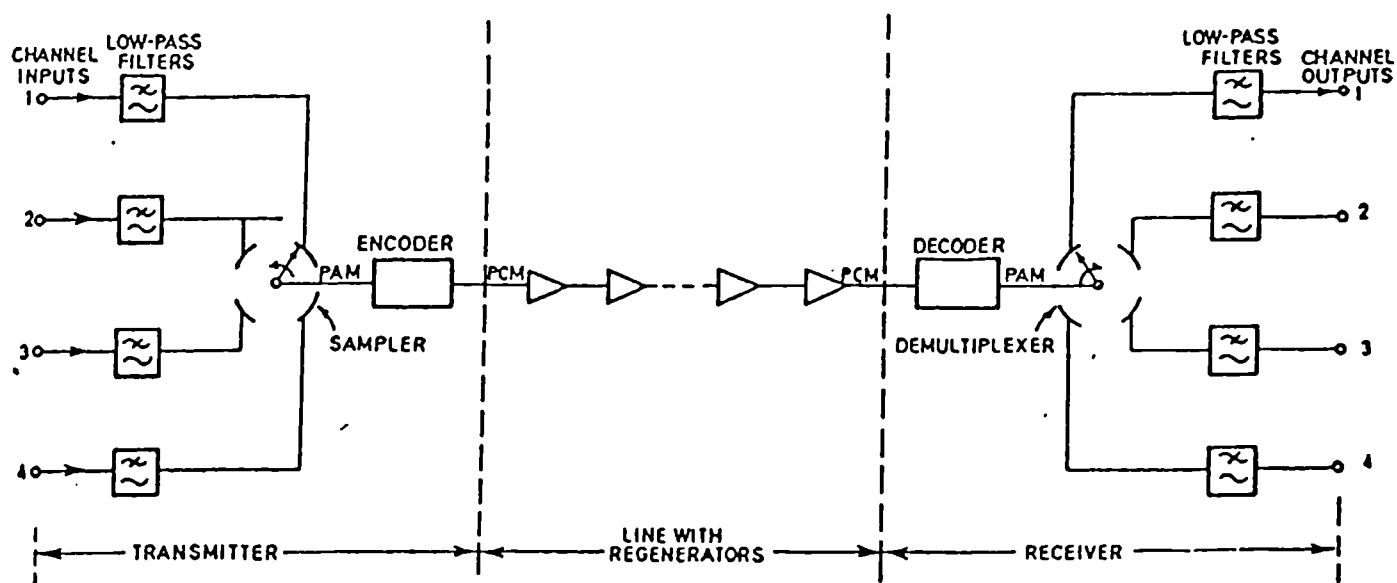
DIGITAL CONTROL offers:

1. High degree of flexibility
2. Enhanced service features and facilities
3. Faster call set up time
4. Improved reliability and quality of service.

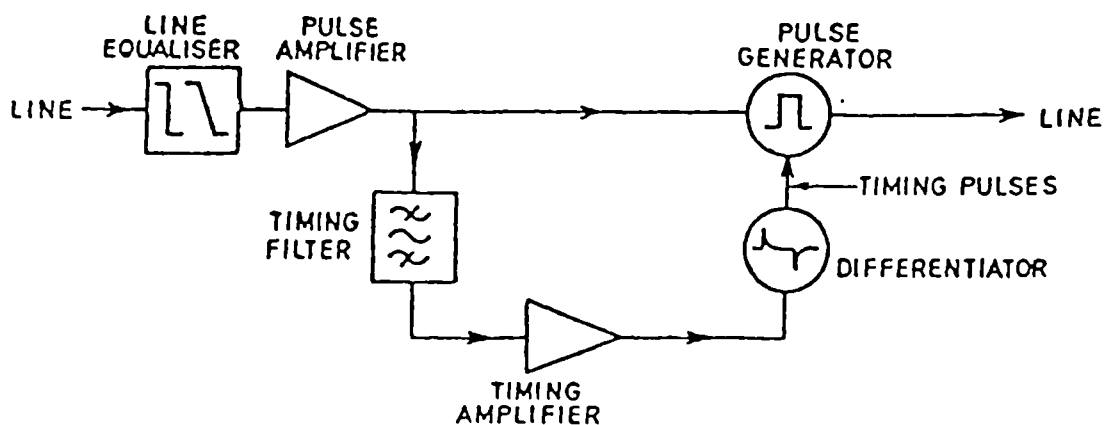
DIGITAL TRANSMISSION offers:

1. A rugged modulation method
2. Stable transmission performance
3. Reduced cross-talk and noise compared with analogue (FDM) transmission
4. High-volume capacity
5. Exploitation of 'new' transmission media, e.g. optical fibre
6. Less dependence on skilled maintenance staff
7. Reduction in circuit costs compared with analogue systems.

## **BASIC ELEMENTS OF A P. C. M. SYSTEM**



Elements of a p.c.m. system



Regenerative repeater for p.c.m.

Fig 1.2

120	recovery system
Terminal	
TIU	Traffic Input Unit
LEN	Line Encoder
LTU	Line Transmit Unit
SC	Supervisory Control
PF	Power Feeding
LNU	Line Receive Unit
LD	Line Decoder
JR	Jitter Reducer
Tou	Traffic Output Unit
Regenerator	
PfF	Power Separation Filter
EAPs	Equalizer Multiplier and Pulse Shaping
LDC	Level Detectors
CG	Coincidence Gates
OS	Output Stages
OEO	Output Equalizer
PCF	Power Combining Filter
SM	Signal Monitor
SI	Supervisory Insertion
TR	Timing Recovery
8.448 Mbit/s OPTICAL FIBRE LINK SYSTEM	
Receive Terminal	
APD	Avalanche Photo Diode
PA	Pie amplifier
EOf	Equalizer and Filter
TC	Threshold Circuit
DR	Digital Regenerator
68/58 68/58 DEC	Decoder
BIN	Binary to
HDB3	HDB3 Encoder
TEX	Timing Extraction
6/5SRC 6/5 Rate Change	
DOC	De mountable Optical Fibre Connector

### Connector

The diagram illustrates the architecture of an 8.448 Mbit/s Optical Fibre Line System, divided into two main sections: the Transmitter Terminal and the Receiver Terminal.

**Transmitter Terminal:**

- Input:** An 8.448 Mbit/s HDDB CODED INPUT signal enters the transmitter.
- Encoding:** The input signal passes through an ENC (Encoder) block.
- Drive Amplifier:** The encoded signal is then processed by a DA (Drive Amplifier) block.
- LED:** The output of the DA block drives an LED (Light Emitting Diode).
- Optical Output:** The LED is connected to an OPTICAL FIBRE TAIL, which leads to the OPTICAL FIBRE LINE.

**Receiver Terminal:**

- Optical Input:** The OPTICAL FIBRE LINE connects to an OPTICAL FIBRE TAIL, which leads into the receiver.
- Photodiode:** The signal enters through a PD (Photodiode) block.
- Transimpedance Amplifier (TIA):** The signal from the PD is amplified by a TIA (Transimpedance Amplifier) block.
- Comparator:** The amplified signal is then processed by a C (Comparator) block.
- Decoder:** The output of the comparator is fed into a DEC (Decoder) block.
- Output:** The final output is an 8.448 Mbit/s CODED OUTPUT signal.

## TIME DIVISION MULTIPLEXING

DIGITAL SWITCHING offers:

1. 4-wire switching without cost penalty
2. Low noise performance
3. Stability of transmission
4. Low fault rate and hence low maintenance cost
5. Fast switching
6. Reduced accommodation requirements
7. Reduced manufacturing and installation costs
8. Decrease in energy requirements

DIGITAL SIGNALLING offers:

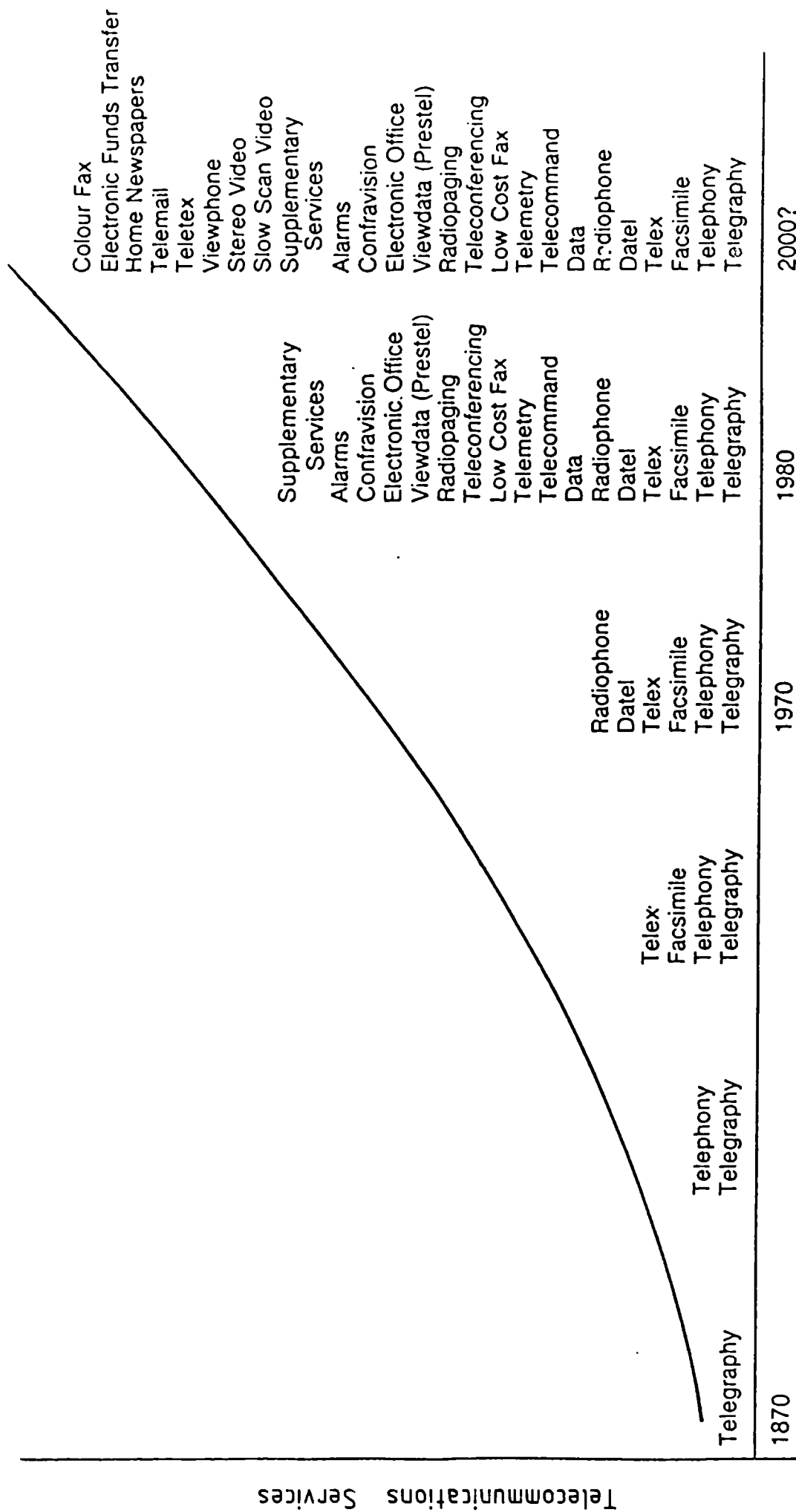
1. Elimination of per-circuit signalling equipment
2. Fast processor-processor signalling
3. Increased signalling repertoire
4. Improved quality of service
5. Flexibility to meet new services

British Telecom recognised that the development of telematics i.e. telecommunications plus informatics (computing, word processing, etc.) together with the move to the office of the future, would require the provision of an 'active' network capable of supporting a host of services. The growth in the UK public network is illustrated in Fig. ( 14 ).

#### 1.3.6

#### Digital Networks on Microwave Link Bearers

Advances in solid state R.F. technology and the application of Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM) techniques now permit digital (P.C.M.) signals to be carried over microwave link bearers. Link capacities of 8Mbit/s in the private user 7.5GHz (RT24) band are typical figures for such equipments.



Growth in Services

Fig 1.4



1.3.7Digital Switch Telephone Exchanges (IDX)

These exchanges use digitally controlled solid state switching techniques and stored programme control in the same way as analogue exchanges but a P.C.M. highway replaces the large number of analogue speech paths.

The system of P.C.M. employed within a digital exchange is 8 bit parallel rather than 8 bit serial as in the 32 channel line system (usually referred to as 30 ch.) and the transmission speed is 4.096Mbit/s instead of 2.048Mbit/s this gives 512 time slots as against only 32.

These 512 time slots are available to all speech and data traffic within the exchange. When an extension makes a call the C.P.U. allocates a time slot to the call, rather than a direct speech circuit as in the analogue switch, and the called extension is connected to the same time slot. This allocation is controlled via the timing and address bus. Of the 512 time slots available on the P.C.M. highway a number are used for system control leaving 420 for traffic, however compared to the 31 discrete speech paths of the Regent<sup>†</sup> it is obvious that the IDX has much greater traffic carrying capacity with 100% non-blocking up to 420 Erlangs. This means that in an exchange of up to 280 trunks and 560 extensions every circuit can be in use simultaneously. The IDX PCM principles are illustrated in Fig. (15).

One of the most important advantages of the digital exchange is its ability to switch data circuits as well as speech. The way in which this is achieved is shown in Fig. (16).

<sup>†</sup> Regent = British Telecom electronic analogue switch type telephone exchange (also known as Mitel SX200)

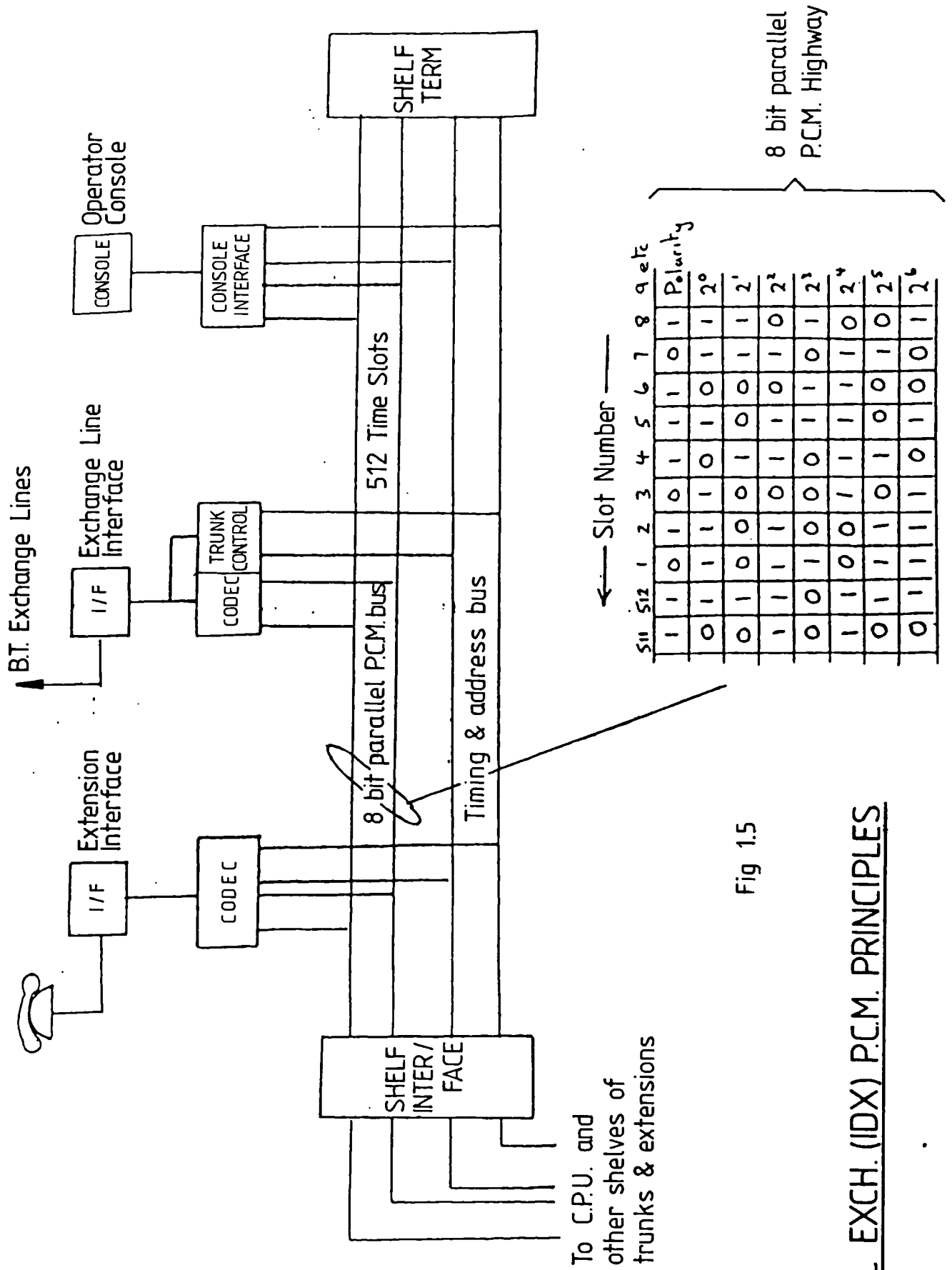
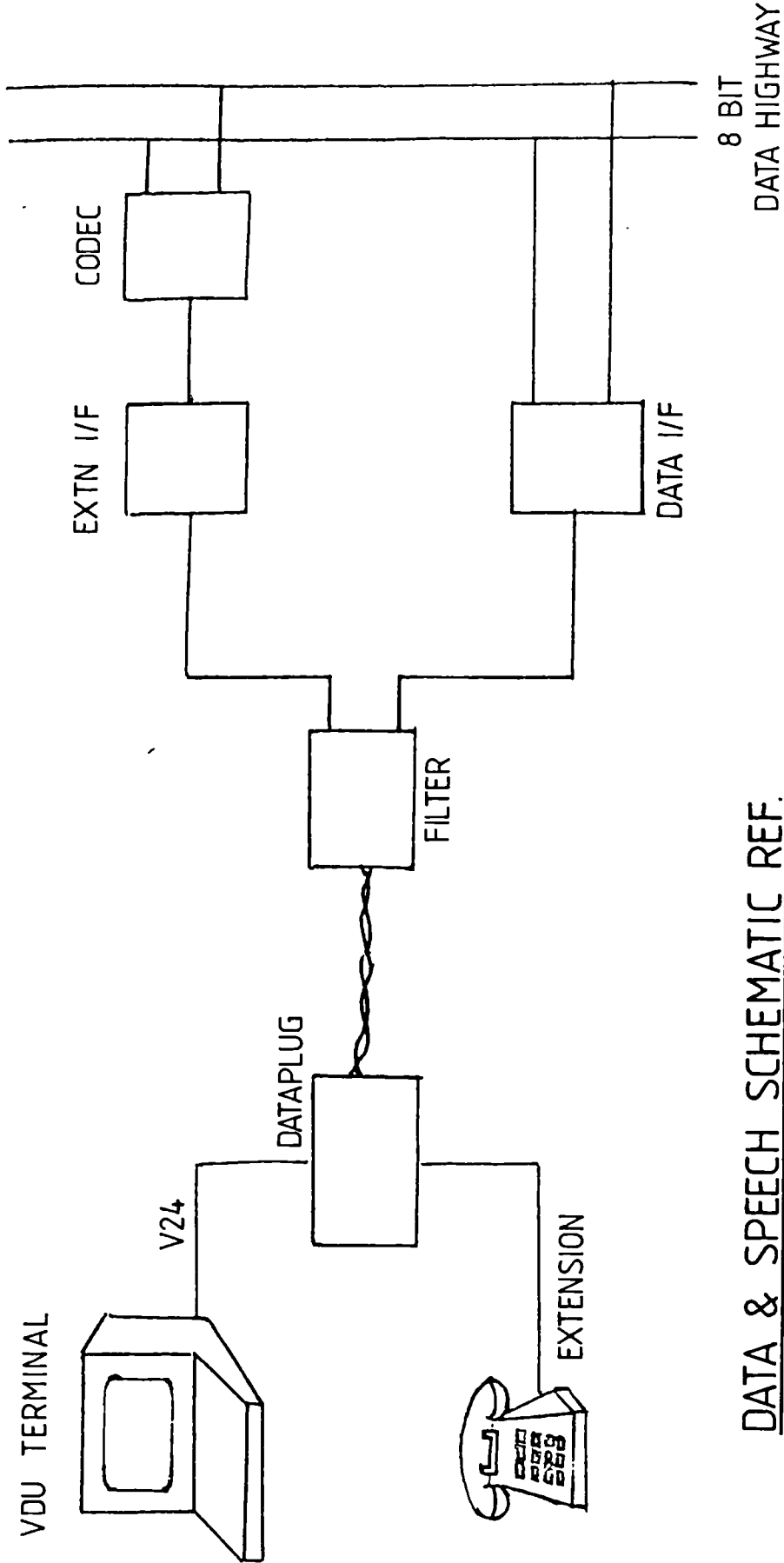


Fig 1.5

## DIGITAL EXCH. (IDX) P.C.M. PRINCIPLES



DATA & SPEECH SCHEMATIC REF.  
THE DIGITAL EXCHANGE (IDX)

Fig 1.6

Information from the VDU terminal is passed in serial form from its V24 interface to the Dataplug. Here it is formed into groups of 32 bits and transmitted as a burst of data at 512Kbit/s. Within the IDX the incoming data is converted into 8 bit parallel format and inserted into one of the 512 time slots for onward connection. The speech in the IDX is also converted into 8 bit parallel data for switching purposes and it is dealt with in exactly the same way as data, this makes the exchange fully compatible for speech and data. By the use of filters it is also possible for a telephone extension and a data terminal to share the same wiring within a building.

It is the digital switch/PCM concepts that form the basis of the majority of large in-house private networks to date.

Digital transmission and switching systems with computer controlled management and remote diagnostics can provide a wide range of facilities integrated within common highways etc. These include ISDN, mailbox, viewdata, facsimile, data, PABX modems and telephone extensions.

#### 1.4

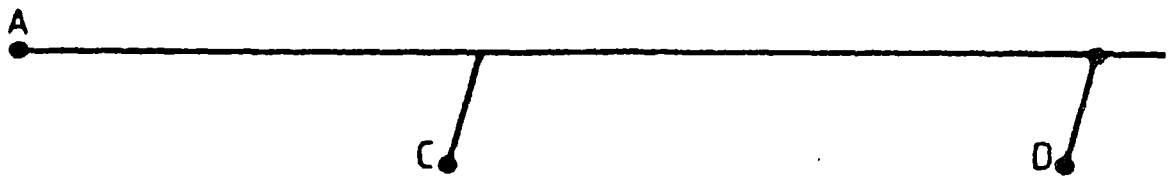
#### Types of Network

Networks consist of two or more locations (nodes) which are connected together using communications links. A node may contain any number of communication and computing devices. A number of special terms are used when describing data links and networks these are illustrated in Figs. N1 to N6.

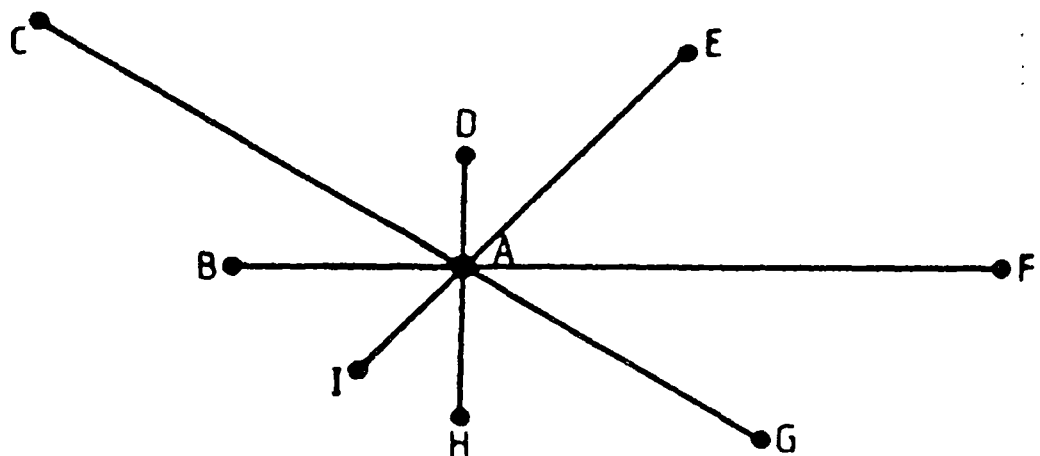
Point-to-Point is the simplest and is extensively used (Fig. N1). It may be transitory and exist only for the duration of a call on the switched network, or exist permanently as a leased circuit.



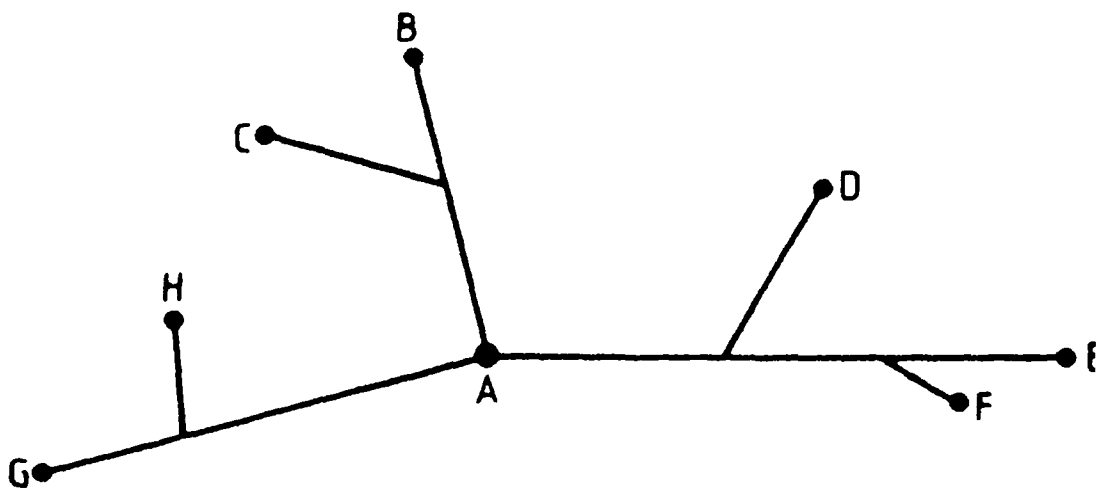
POINT-TO-POINT DATA LINK



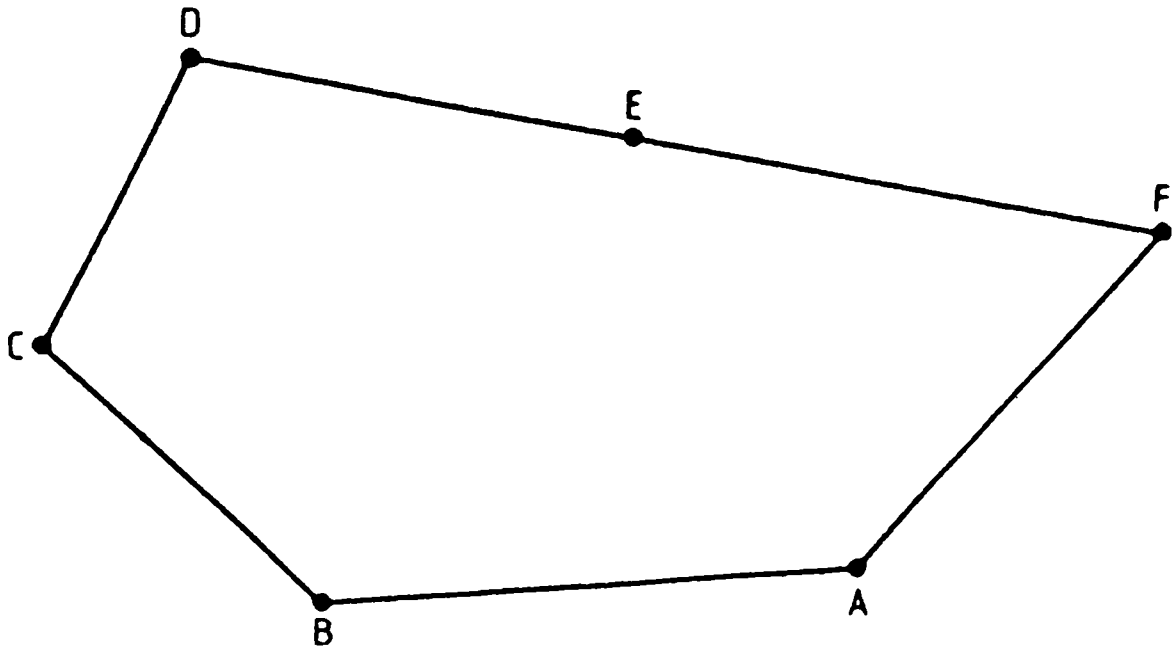
MULTIDROP DATA LINKS



STAR NETWORKING USING POINT-TO-POINT CIRCUITS

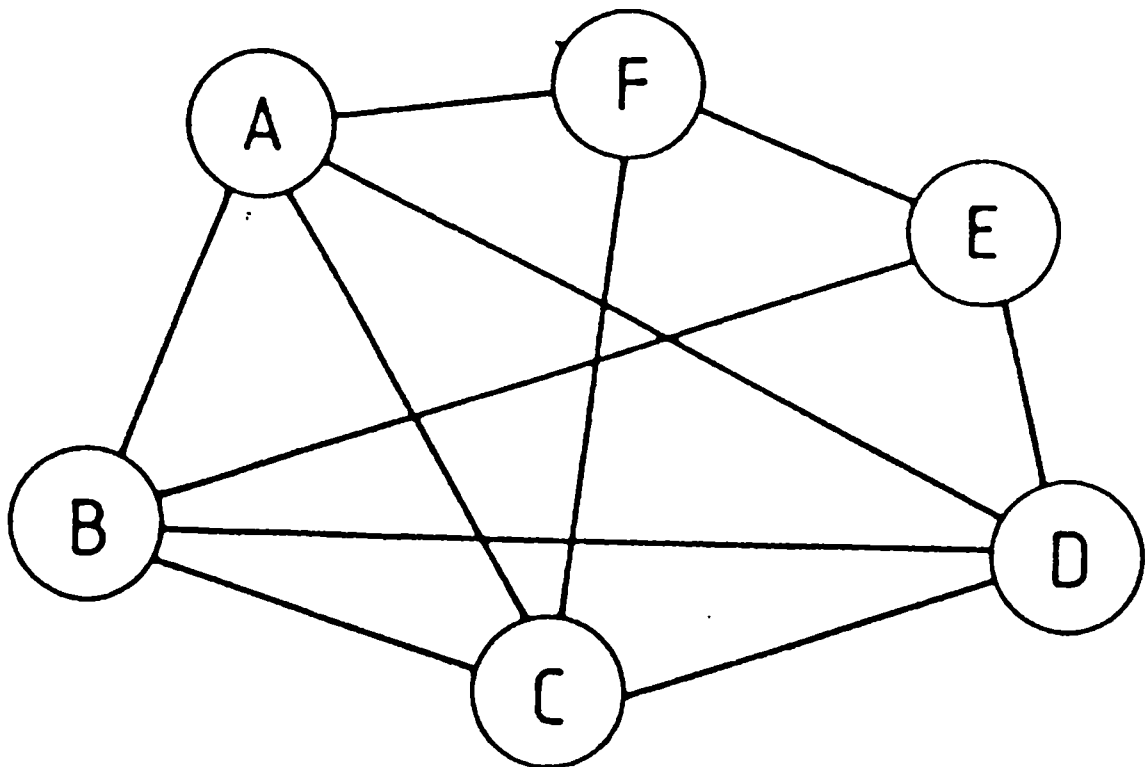


MULTIDROP STAR NETWORK



N5

A CLOSED-LOOP OR RING NETWORK



N6

A MESH NETWORK

Multidrop is utilised where a large number of locations have to be connected, and these can be broken down into geographical clusters. The multidrop form of configuration is generally more cost-effective (Fig. N2).

Star Configurations are utilised for communications from a central site (mainframe computer) to remotely sited terminals. Most configurations of this type reflect the early evolutionary stages of the computer and data communications. The star configuration has major limitations as the network is very vulnerable to failure, either of the central computer or communication front end processor or the single transmission links or highways. Mesh networks and loop networks help to overcome these problems.

Loop configurations (Fig. N5) provide the ability of supporting transmission in both directions. In the event of a single link being broken communications can still be maintained. Two links will need to be broken before one or more nodes becomes isolated.

Mesh Networks (Fig. N6) provide a high degree of resilience to failure, with alternative routes being available when data link failure occurs. With a real-time computer controlled management system the users may be unaware that a network failure has occurred.

#### 1.4.1

#### Wide Area and Local Area Networks

Local Area networks are designed specifically for the interconnection of computer systems and terminals within a single geographical site (typical bandwidth 10Mbit/s utilising coaxial or fibre optic cable). They utilise simple protocols, have a relatively low installation cost and a uniform method of attachment for diverse types of equipment i.e. plug compatibility.

Wide Area Networks such as the public switched telephone network (PSTN) is used extensively for data communications. Normal dial-up circuits are employed and consequently the quality of established circuit varies. Depending on the distance involved and the total length of connect time, the use of the PSTN on a day-to-day basis may be expensive and a leased line or private circuit justified.

#### 1.4.2 Packet Switching

This is a method of routing data through a communications network. The user transmits packets of data with fixed formats and a limited size to a nearby packet switching centre. The centre then routes each packet along the network to another centre near the destination.

#### 1.4.3 Modems and Statistical Multiplexers

1.4.3.1  
Modem (general term). The Modulator and DEModulator. Used to process a digital signal into a form suitable for transmission over an analogue transmission network.

1.4.3.2  
Baseband Modem. A modem whose digital input (or simple transformation of it) is applied to the transmission channel. No complex modulation takes place before transmission. This type of modem requires a channel with a very wide bandwidth and has a very limited range.

1.4.3.3  
Multiplexer. A device which divides a data channel into two or more independent data channels of lower speed.



1.4.3.4

Statistical (Time Division) Multiplexers. This device extends the concept of character-interleaved Time Division Multiplexing. Rather than allocate high-speed channel capacity in a fixed manner with each low-speed channel being allocated its share whether it needs it or not, a statistical mutliplexer will monitor each of the slow-speed channels at the rated speed of that channel but only use high-speed channel capacity when there is data to be transmitted. When the low-speed channels are lightly utilised, it is possible for the multiplexed link (in the network) to handle data from slow-speed channels with aggregate data rates far in excess of that of the high speed channel. As the combined data rates of the low-speed channels exceed that of the high-speed channel, it is possible for the data-flow from the slow-speed channel to exceed the throughput capability of the multiplexed links in the network. To cope with this eventuality, statistical multiplexers contain large buffers which are capable of absorbing short-term peaks in demand.

1.4.3.5Resilient Data Connections

Not only is it necessary to consider alterantive routing in a network (i.e. 'mesh' and 'loop' construction) it is also necessary to maintain Resilient Data Connections within individual nodes. Fig.(17) illustrates one possible configuration for currently available trunk networking hardware interconnected to provide a high degree of resilience. The subject of resilience is investigated, in detail, in chapter 7.

# THE AREA NODE

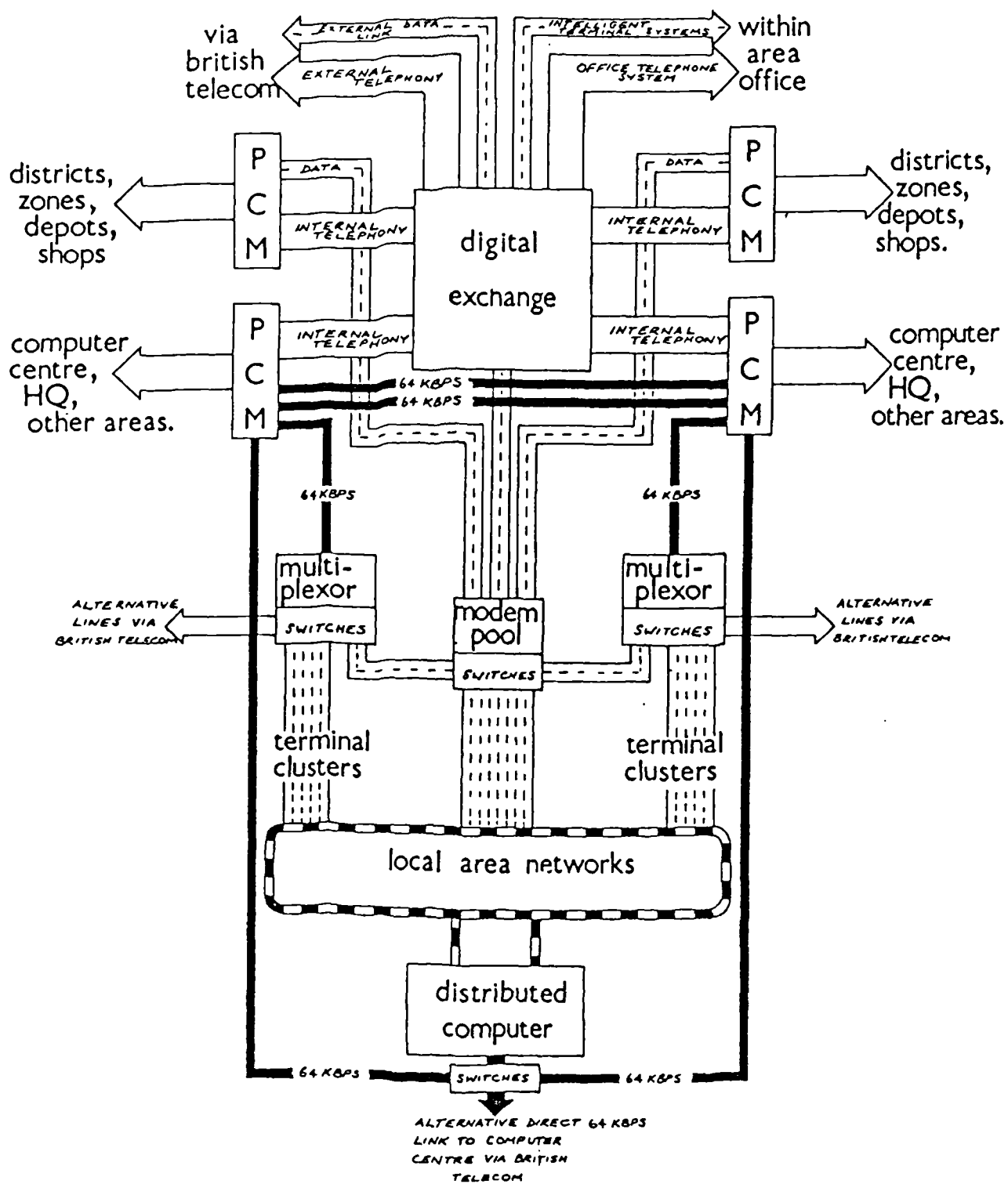


Fig 1.7

1.5The NORWEB Trunk Network

The current trunk network within Norweb's urban areas consist of 24 and 30 channel PCM systems supplemented, in the major rural areas, by 36 channel analogue FDM microwave link systems.

The network is continually adjusting to cater for new user requirements and to take advantage of the cost benefits offered by the latest technological developments including; digital microwave, laser and optical fibre systems.

Norweb Electricity commenced the installation of 24 channel PCM systems in the early 1970's because they provided the most cost effective solution to their future telecommunications transmission requirements. In 1976 analogue microwave links were also established in Lakeland Area utilising 12 & 24 channel FDM techniques.

The decision to implement PCM was governed originally from the fact that Norweb had available unloaded telephone and pilot cables of mixed sizes and types which lend themselves to the less critical requirements of PCM digital techniques rather than the more rigorous criteria demand for analogue FDM systems. For short distances up to 32km PCM systems are attractive, where the low cost of terminal encoder/decoder equipment is combined with a limited number of relatively expensive regenerator stations. Frequency division multiplex systems employ expensive terminal multiplexing items but enjoy relatively less expensive line amplification plant. PCM was, therefore, the ideal system to use on a short distance between terminals, mixed specification bearer (cable) network. An additional inducement to adopt PCM was that regenerator stations could be accommodated within distribution substations along the route. A distance of 1.8 km between regenerator sites is typical and by careful selection they

have been made to coincide with substation sites in a large number of cases. In the major rural areas of Norweb where the pilot cable systems had not been developed analogue microwave systems with FDM multiplexing became the obvious choice.

The basic geography of Norweb is illustrated in Fig. (1.8), including a number of the Board's showrooms. Essentially Lakeland Area is rural compared with the other Areas of Mid Lancashire, South Lancashire, Peak Area and Manchester which are in the main urban. The mainframe computers are located at Manchester as are the Transmission Control Centre (33/132kV NTCC) and the Reporting Centre (NRC).

The current 24/30CH PCM network is illustrated in Fig. (1.9). Each 24 channel route is identified with a three digit number commencing with a '2' similarly each 30 channel route is identified with a three digit number commencing with a '3'. Note the 'mesh' and radial components of the network.

Typical multiplexing configurations at an area node (Area Office) are illustrated in Fig. (1.10). These include the lower order elements of the network which may utilise rented point to point circuits to serve showrooms etc. The system data node essentially cascades from 6 x 64Kbit/s PCM channels to a possible 36 x 9.6Kbit/s data channels to various 2.4, 4.8 or 9.6Kbit/s local terminals or via statistical multiplex units to remotely sited terminal equipments. Also the 30CH PCM terminal provides trunk interconnection for the local digital switch PABX (Plessey IDX).

The microwave link FDM based northern half of the trunk network is illustrated in Fig. (1.11). Note the 'ring' configuration utilised. The 1.5GHz microwave links provide 36 channel capability with 8 and 12 channel groups off to the Area Offices and depots. The system is supplemented, where necessary, with rented point-to-point circuits.

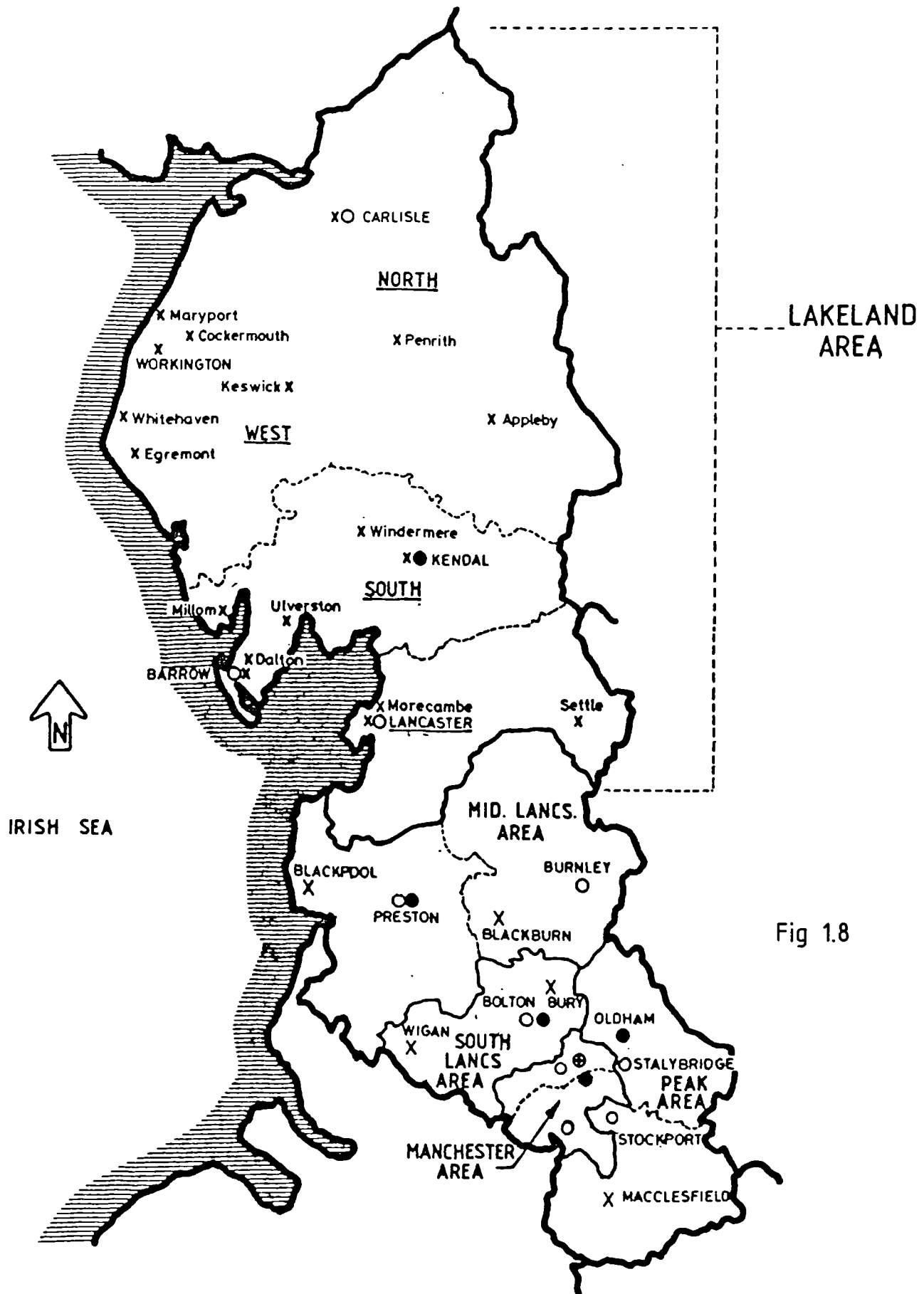


Fig 1.8

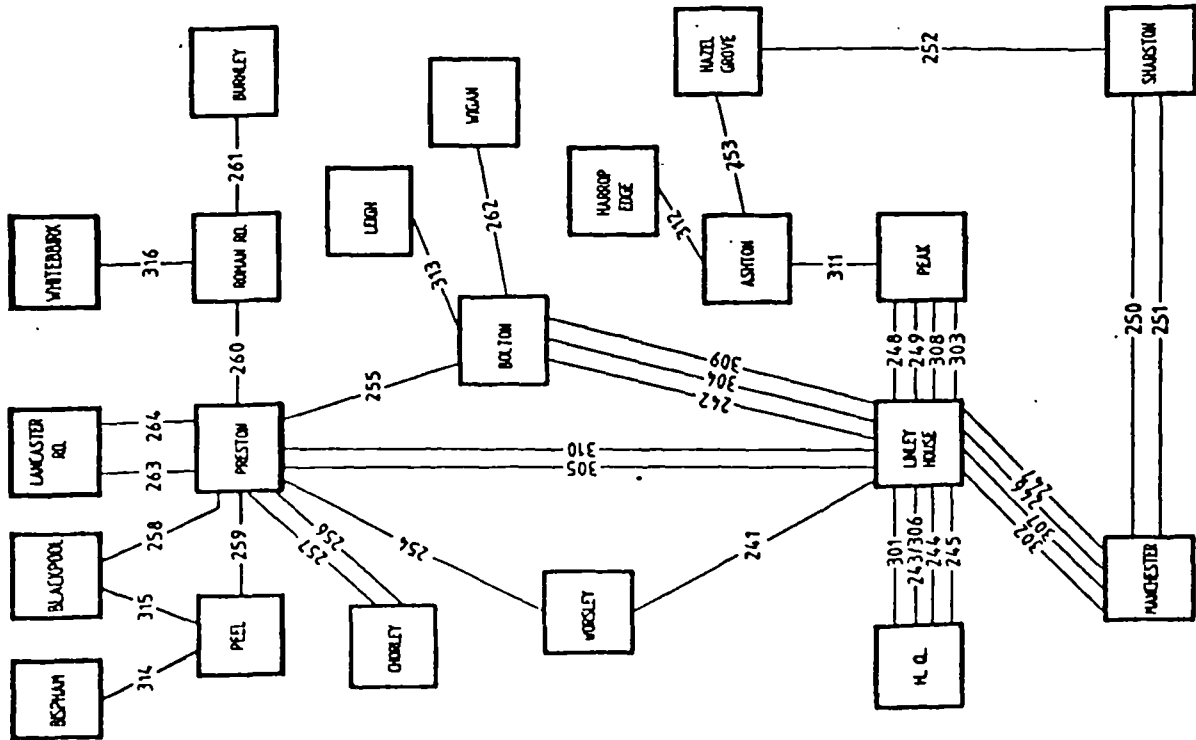


Fig 1.9

30 ch PCM LINE ROUTES			24 ch PCM LINE ROUTES		
		VIA			VIA
301	LINLEY - H.Q.	ANCOATS NORTH	261	LINLEY - WORSLEY	AGECROFT
302	LINLEY - MANCHESTER	PRINCESS ST.	262	LINLEY - BOLTON	AGECROFT
303	LINLEY - PEAK	NEW MOSTON	263	LINLEY - H.Q.	ANCOATS NORTH
304	LINLEY - BOLTON	AGECROFT	264	LINLEY - H.Q.	BLACKFRIARS
305	LINLEY - PRESTON	AGECROFT	265	LINLEY - H.Q.	ANCOATS NORTH
306	LINLEY - H.Q.(H)/EX243	ANCOATS NORTH	266	LINLEY - MCR.	PRINCESS ST.
307	LINLEY - MANCHESTER	UNIVERSITY	267	LINLEY - MCR.	UNIVERSITY
308	LINLEY - PEAK (ex248)	FAIRSWORTH	268	LINLEY - PEAK	FAIRSWORTH
309	LINLEY - BOLTON	PARRIN LANE	269	LINLEY - PEAK	NEW MOSTON
310	LINLEY - PRESTON	PARRIN LANE	250	MCR. - SHARSTON	SHURLEY INST.
311	PEAK - ASHTON		251	MCR. - SHARSTON	NORTHENDEN PUMP
312	ASHTON - HARROP EDGE		252	SHARSTON - HAZEL GROVE	
313	BOLTON - LEIGH (#NOTHS 43)		253	ASHTON - HAZEL GROVE	
314	PEEL - BISPHAM		254	WORSLEY - PRESTON	
315	PEEL - BLACKPOOL		255	BOLTON - PRESTON	
316	ROMAN RD. - WHITEBIRK		256	PRESTON - CHORLEY	
			257	PRESTON - CHORLEY	
			258	PRESTON - BLACKPOOL	
			259	PRESTON - PEEL	
			260	PRESTON - ROMAN ROAD	
			261	ROMAN RD - BURNLEY	
			262	BOLTON - WIGAN	
			263	PRESTON - LANCASTER RD.	HOLME RD.
			264	PRESTON - LANCASTER RD.	

NORWEB P.C.M. LINE ROUTES

# TYPICAL CASCADE MULTIPLEXING CONFIGURATIONS AT

## AN AREA NODE

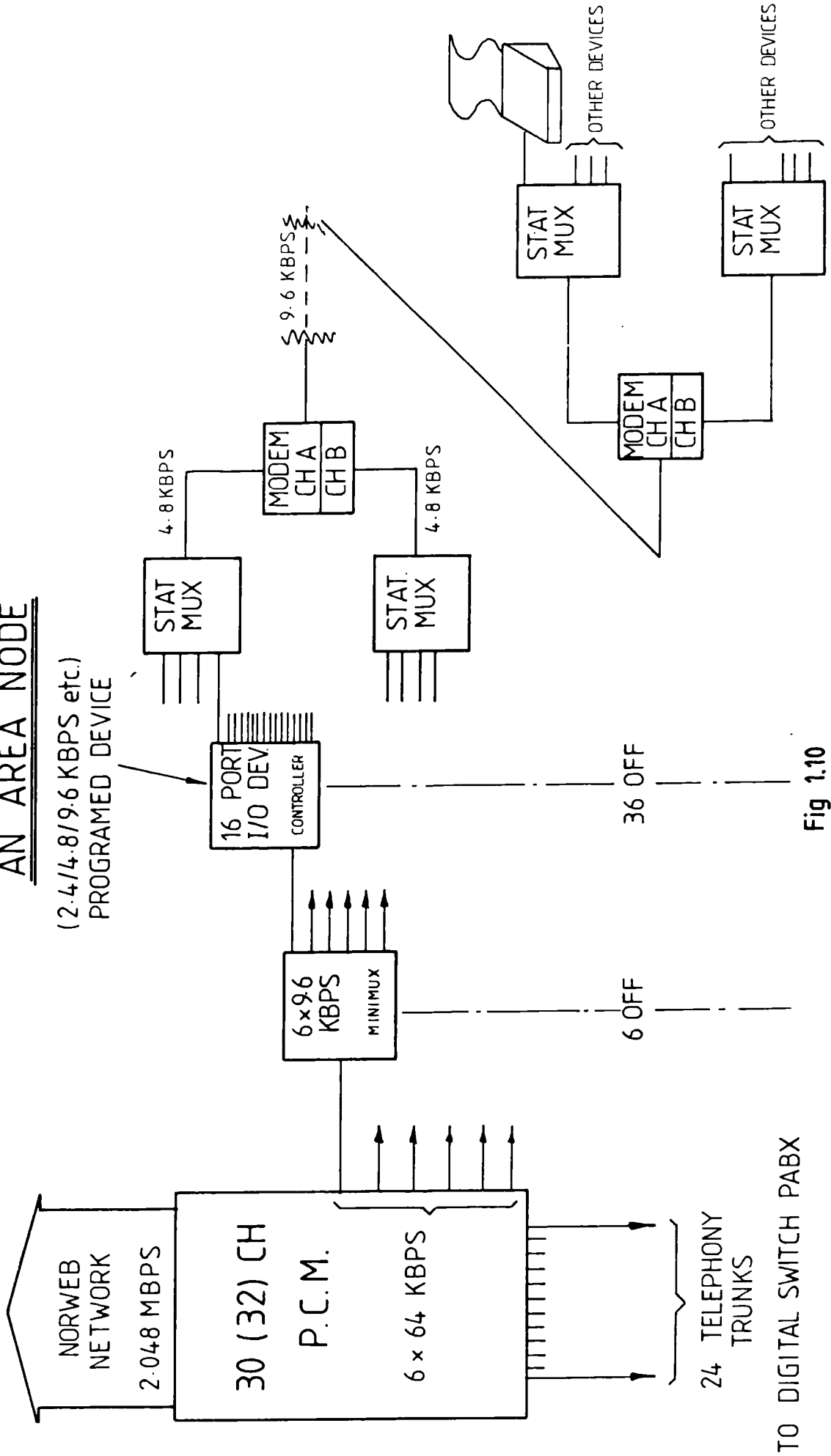
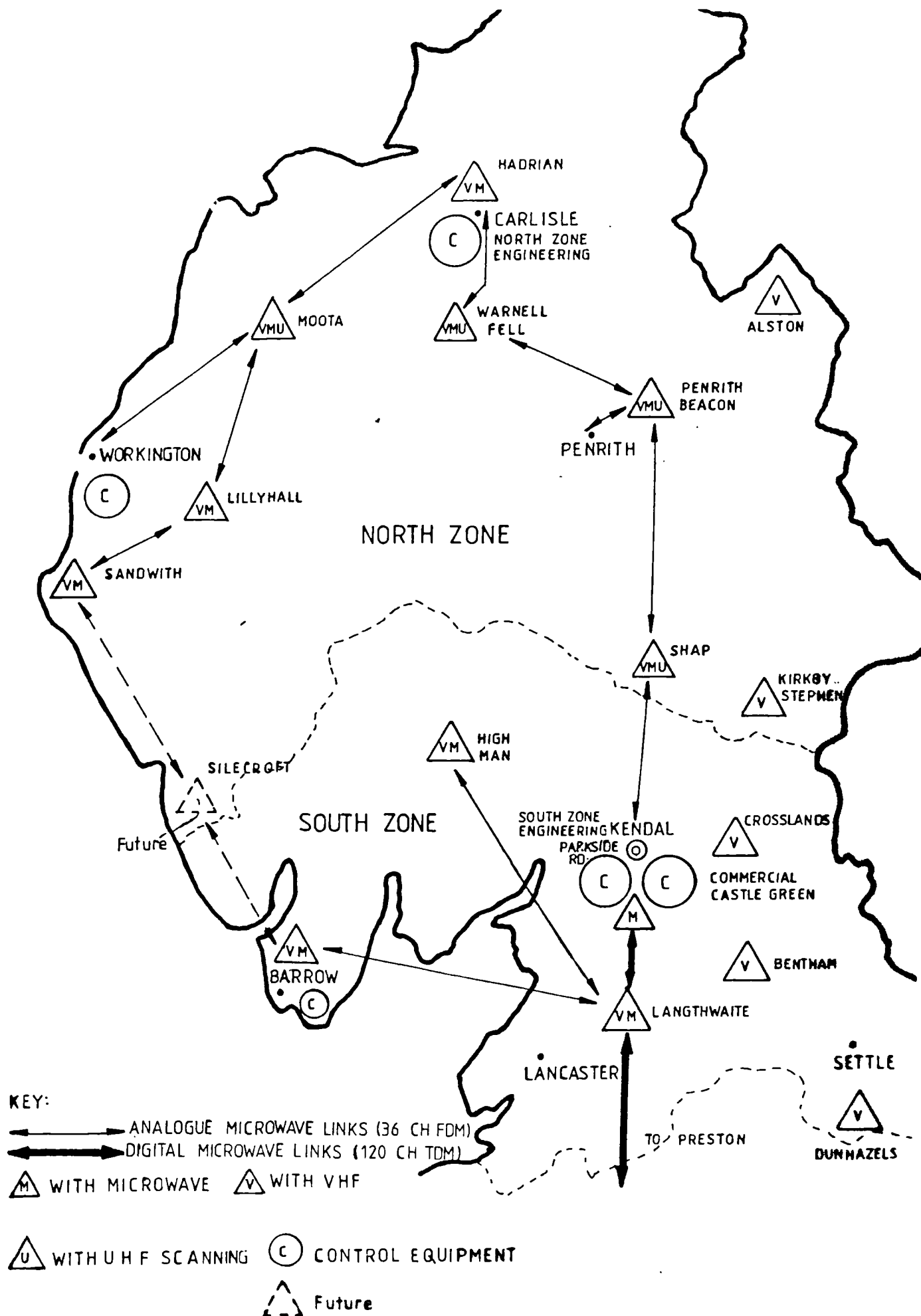


Fig 1.10

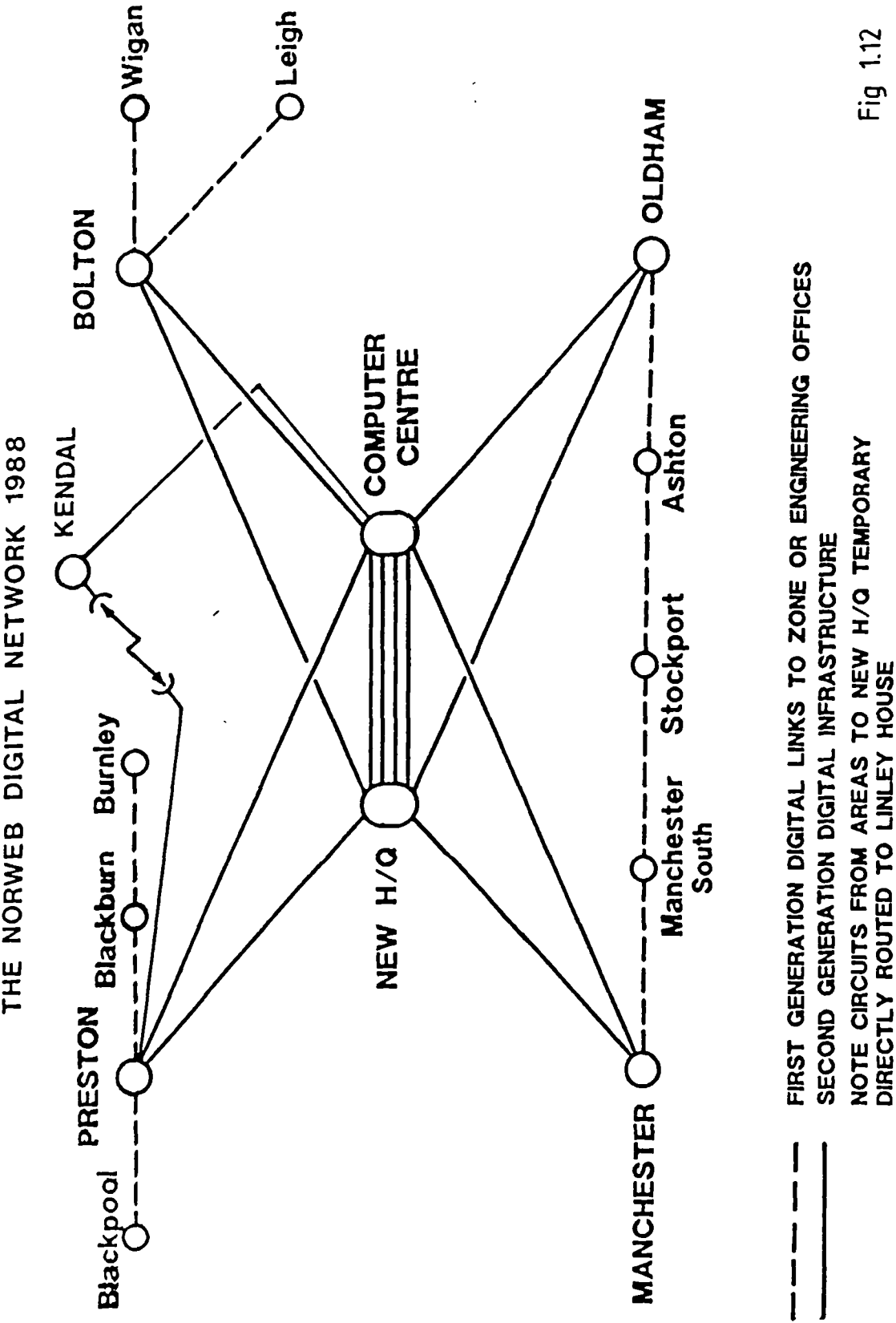
Fig 1.11 Lakeland Area Radio Network (NORWEB)



1.5.1The NORWEB Trunk Network 1988

Fig. (1.12) illustrates the trunk network by 1988. This includes a more resilient mesh configuration based on second generation 30ch. PCM and digital microwave to Lakeland Area with 'Megastream' alternative routing. Each main area office node has two independent links to the network and Board HQ and the Computer Centre have four independent links

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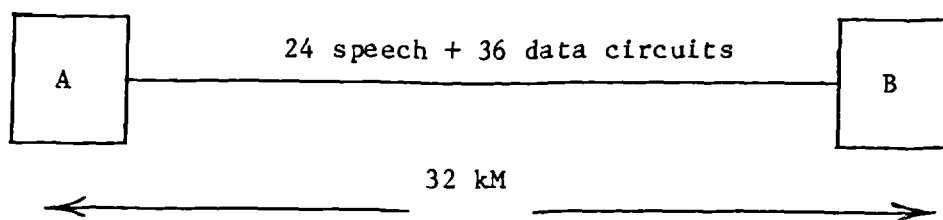


1.6Economics of PCM installation

The economic case for installing 30 channel PCM as telecommunications links between locations in an urban environment is most favourable for the ESI because of its unique position as the owner and maintainer of a private telephone cable network. Often old cables containing a small number of pairs can be utilised to provide adequate numbers of telephony and data circuits at moderate cost.

Comparison between ESI PCM and equivalent BT services.

Example use a 32km point to point link requiring 24 speech circuits and 36 9k6 data circuits.



1.6.130 Channel PCM Hardware Costs

## MULTIPLEX

		£	£
20 regenerator	@	162	3240
48 2w/4w E&M card	@	105	5040
6 data access card	@	250	1500
2 multiplex	@	2432	4864
2 line term unit	@	505	1010
2 line shelf	@	300	600
2 cabinet	@	484	<u>968</u>
			£17222

## REGENERATOR SITE COSTS

20 site work	@	250	5000
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## TDM MULTIPLEX

2 TDM data MUX	@	950	<u>1900</u>
			£24122

ENGINEERING ONCOSTS	@ 25%		<u>6030</u>
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GRAND TOTAL £30152

1.6.2BT Private Wire & Kilostream Annual Rental Costs

## ANALOGUE B

		£	£
24 speech circuits	@	1230	29520

## KILOSTREAM

36 9600 bits/sec data circuits	@	2276	<u>81936</u>
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GRAND TOTAL 111456

NOTE: The above rental charges for BT services do not include connection charges. Source of the above data BT Kilostream Tariffs 1985.

1.6.3Cost Comparison Summary

PCM costs are a once only cost and do not include any contribution for cable provision. It is assumed that existing cable pairs would be used. New 19pair telephone cable laid in a high density urban environment has an installation cost of £21,000 per km (1985 actual example).

	<u>BT Rented Services</u>	<u>ESI PCM</u>	<u>Difference</u>
1st year cost	£111,456	£30,152	£81,304
Subsequent years	£111,456	NIL	£111,456

It can be seen that the cost savings are of a high magnitude, but may be considered fictitious because of the lack of cable provision costs.

Using the above example of a 32km route a new 19pair cable could be laid and paid for from the cost differential in a period of 6.4 years.

Although the above example uses simplistic accounting calculations, it amply demonstrates the cost benefits of "in-house" PCM provision.

### 1.7 Optical Fibre Transmission

PCM transmission via optical fibre bearer is currently being evaluated using multimode fibre. Up to 17km spacing between equipments is possible when working at 1300nm wavelengths. Greater distances can be covered if intermediate regenerator stations are employed. These can be constructed using two optical terminal cards connected back to back.

Second, third and fourth order multiplex optical systems are available but it seems unlikely that any third (480 channel) or fourth (1920 channel) systems would be required within the ESI to meet a firm traffic requirement as of 1987. The combining of 4X2.048 Mbits/s systems via a second order MUX is, however, a likely possibility within the industry. Norweb are actively considering the option to interconnect their Computer Centre with a new HQ site.

### 1.8 Power Line Carrier (Overhead Power Transmission Networks)

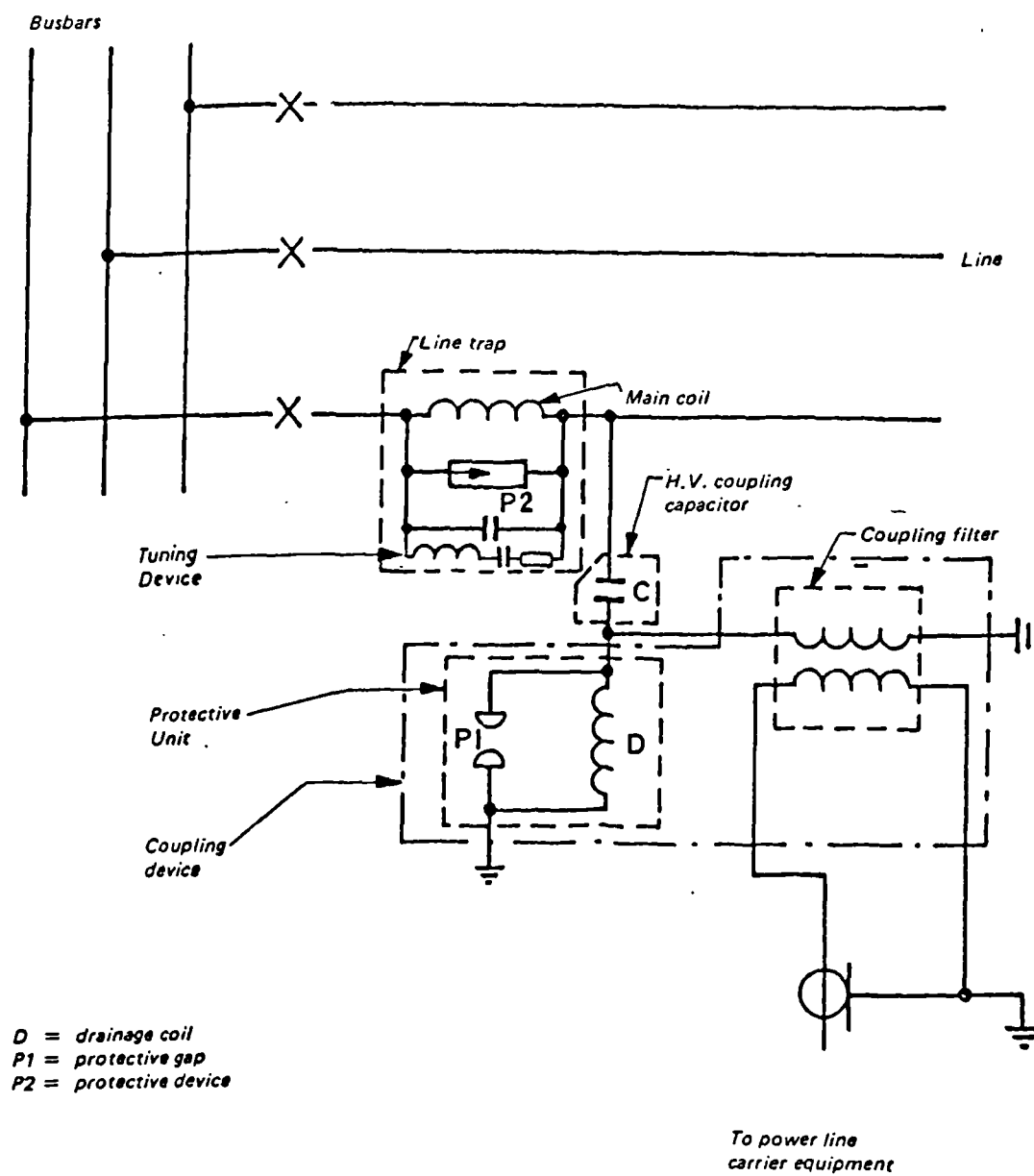
The High Voltage Power Lines (usually 132kV and above) used by Electricity Supply Authorities are a very attractive medium for communications. The lines themselves are physically very robust and the reliability is therefore very good.

Coupling equipment has to be provided to safely connect the Power Line Carrier (PLC) terminal to the High Voltage lines with low loss. PLC frequencies usually lie in the 40 kHz - 500 kHz band which is quite high when compared with the 50 Hz power frequency. The ratio between the powers involved are also very high - many Megawatts being carried at power frequencies whilst the received power level at the PLC receivers is less than a watt.

The basic elements of the coupling equipment consist of a coupling capacitor which is connected between the PLC equipment and the line. Typical values are of the order of 2000 - 4000 pF. A device known as a "line trap" is connected in series with the power and the substation. The simplest and least cost system is the single phase and earth arrangement shown in Fig (1.13 ).

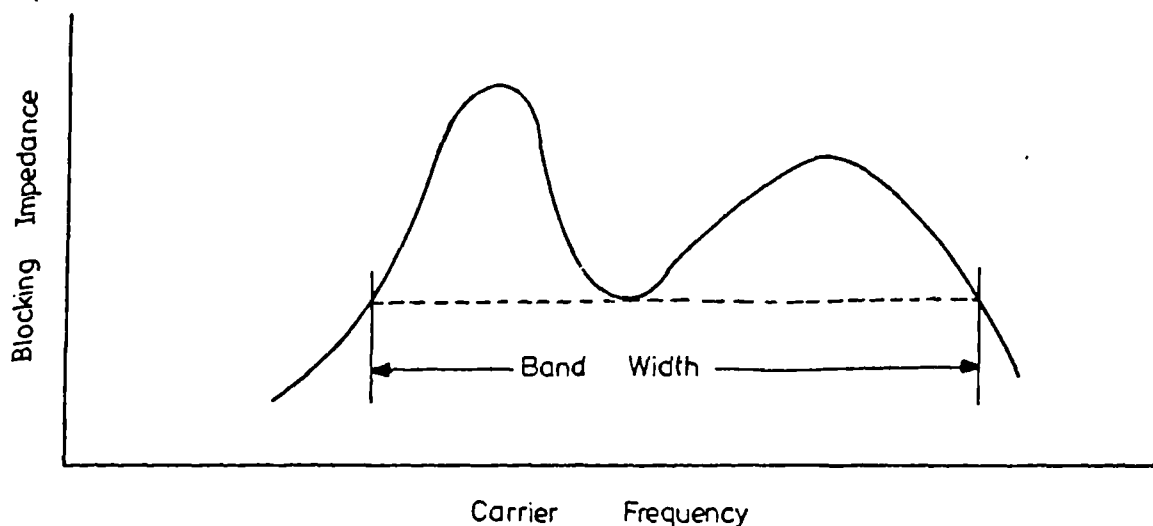
The function of the line trap is to act as a blocking device to the PLC frequencies and to permit PLC operation even in the event of the station busbars being earthed. Inductance values of between 0.2 mH and 2 mH are used. However the impedance of the system beyond the busbars is variable and depends on line configuration and switching conditions. In the most unfavourable case the reactive components of this impedance could neutralise the impedance of the line trap and thus shunt the PLC signal. The tuning device which includes a resistive element, ensures that the minimum blocking impedance is acceptable over the required frequency range. A typical characteristic for a line trap is shown on page 38.





SIMPLIFIED CIRCUIT OF PHASE-EARTH PLC COUPLING ARRANGEMENT

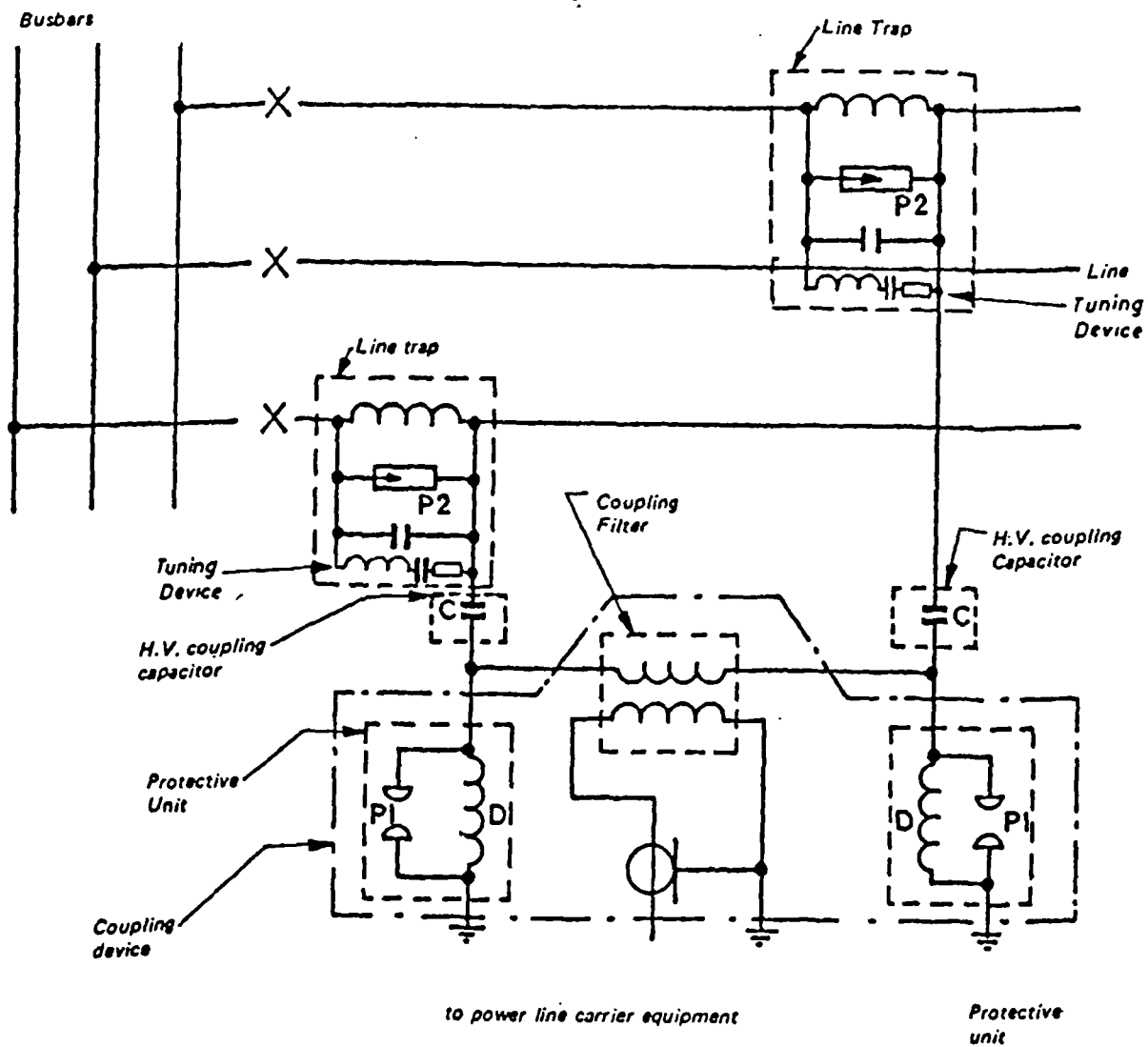
Fig 1.13



The full current of the power line is carried by the line trap. This can be in excess of 1kA under normal operation. Under short circuit condition this can increase to over 30kA RMS with a peak value of 80kA. The line traps are designed to withstand the considerable electromagnetic and thermal forces involved. The traps are normally mounted on top of pedestal insulators.

The function of the drain coil, which is designed to offer a low impedance at the power frequency and a high impedance at PLC frequencies, is to provide a path to earth for the power frequency current through the capacitor and so to limit the potential of the capacitor terminal at the point of connection to the carrier equipment in the interests of safety.

The most common arrangement used is phase-to-phase coupling as shown in Fig. (1.14). Phase-to-phase coupling is preferred as a balanced transmission line is produced and, as a result, electromagnetic radiation from the conductors is minimised. Also the resulting transmission impedance in this configuration approximates to 600 ohms which tends to simplify planning calculations being a common telecommunications network standard.



*D* = drainage coil  
*P1* = protective gap  
*P2* = protective device

SIMPLIFIED CIRCUIT OF INTERPHASE PLC COUPLING ARRANGEMENT

Fig 1.14

Characteristic Impedance of a Power Line

This is given by the expression :

$$Z = 276 \log \frac{d}{r} \text{ ohms}$$

where  $d$  = separation of conductors in metres and

$r$  = radius of conductors in metres.

For phase-to-phase coupling this gives a value of between 650 and 800 ohms.

The influence of the earth tends to reduce these values so that the "classical" figure of 600 ohm characteristic impedance may be used for planning purposes.

1.8.2Attenuation of Overhead Power Line

The attenuation of overhead power lines is strongly dependant on the ratio  $d/h$  where  $d$  is the mean distance between conductors and  $h$  is the mean ground clearance at the towers. A typical figure is 0.05 dB/km. This figure increases with frequency. It also increases with hoar frost or with ice build-up.

1.8.3Noise Level on Power Lines

Corona noise, which is made up of a multitude of independent individual discharges, is fairly constant and uniform across the frequency range used in PLC transmission (40 kHz - 500 kHz).

It is weather dependent and is lowest during dry weather. In foggy and damp conditions the noise in an audio channel is typically, for a 4 kHz bandwidth, - 35 dBm for a 110kV line and - 20 dBm for a 220kV line, figures supplied by ESB (Electricity Supply Board Ireland). Corona discharges depend on the gradient of the electric field on the conductors. Bundled conductors are used above 220kV and the corona noise increase is not as great. These figures are valid for adverse atmospheric conditions.

Noise due to lightning strikes and switching operations also result in a very broad noise spectrum. While this does not greatly affect speech communication it can seriously affect the reliability of high-speed protective relaying terminals which must be designed to cope with this type of interference.

#### 1.8.4

#### Type of PLC equipment used

Single Side Band (SSB) equipment is used with a typical Peak Envelope Power (PEP) of 10W (+40 dBm) to the line. Speech is limited to a bandwidth of 300 Hz to 2.4 kHz which is less than the CCITT bandwidth of 300 Hz to 3.4 kHz. Intelligibility does not suffer appreciably but it is more difficult to immediately recognise a speaker on a reduced bandwidth channel as accents tend to be muted. A pilot tone of 2500 Hz is used for Automatic Gain Control (AGC) and as a telephone signalling channel. The band above 2600 Hz can be used for Voice Frequency Telegraphy (VFT) channels operating at 50, 100 or 200 Bauds. The overall bandwidth extends to 4kHz but the additional bandwidth above the CCITT 3.4kHz limit cannot be used if alternate or standby circuits are designed to the CCITT standard. The

level of the various channels are selected on a voltage/bandwidth basis so that the total PEP of +40 dBm is not exceeded as follows:-

50 Baud VFT channel	+13 dBm
100 Baud VFT channel	+16 dBm
200 Baud VFT channel	+19 dBm
2100 Hz Voice Channel	+37 dBm

### 1.8.5

#### Range of Power Line Carrier Systems

The range of Power Line Carrier Systems is determined by the transmitter power, coupling loss, line attenuation, bandwidth, and corona noise. The following example applies for the speech band on a 220kV line:-

Transmitter Power (speech)	+37 dBm
Coupling Loss (both ends)	- 5 dB
Corona Noise in a 2.1 kHz band	- 23 dB
Line Loss 200 km	- 10 dB

This gives a signal to noise ratio of 45 dB. It should be noted that this is a worst case figure and takes into account bad atmospheric conditions. Normally the signal to noise ratio would be higher.

### 1.9

#### Power Line Systems (Underground Power Distribution Networks)

As with overhead power transmission networks the lower voltage underground distribution networks may be utilised for telecommunications purposes. Early mainsborne signalling systems were employed for the switching of street lighting and more recently for tariff switching and general telecontrol, in particular, by the Jersey Electricity Company Ltd.

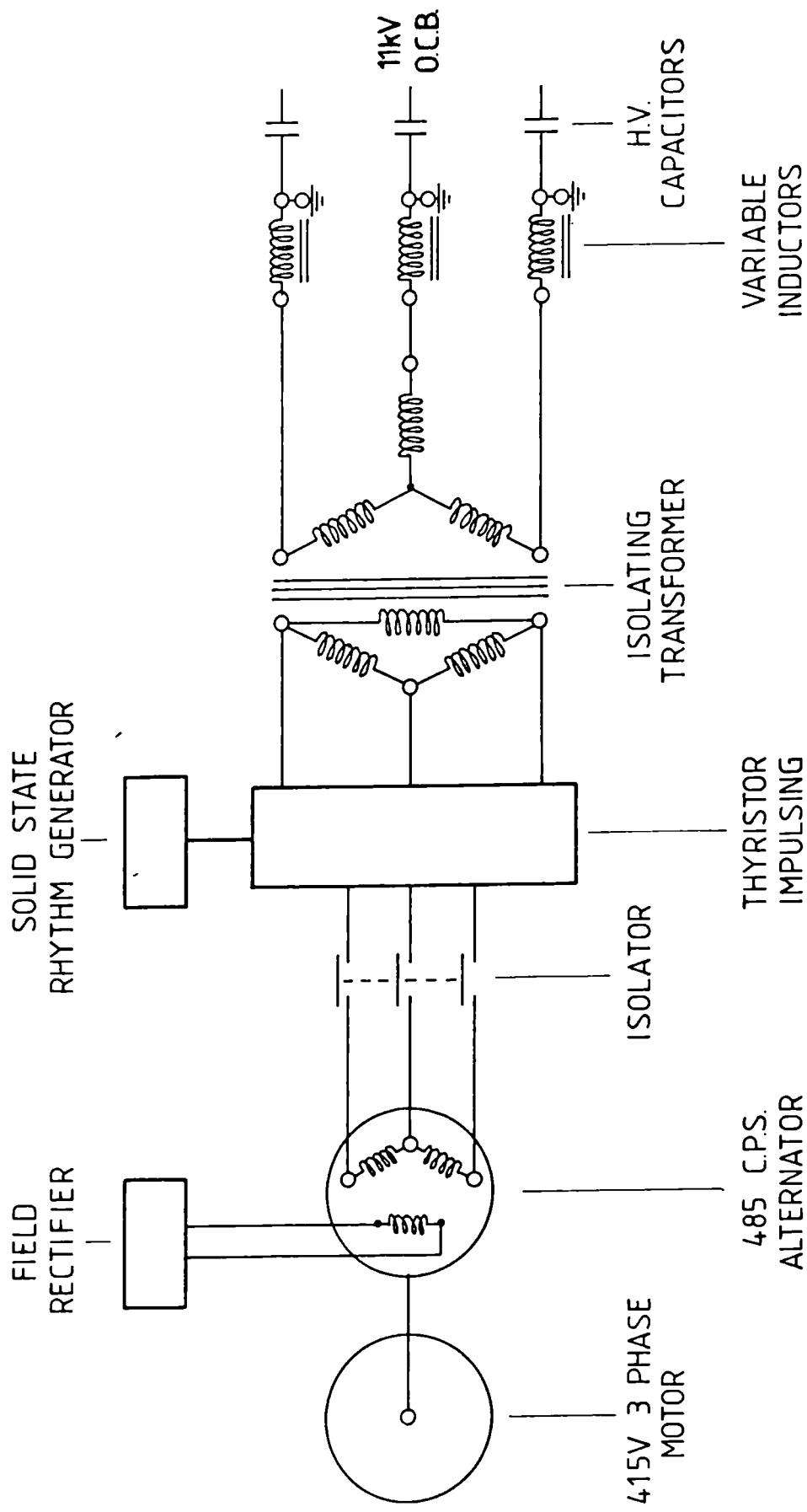
1.9.1Ripple Systems (Audio Frequency Injections)

'Ripple Control' is a centralised control system of remote switching for distribution networks. An audio frequency signal voltage is superimposed on the main voltage and transmitted along the normal distribution cables, - which supply the power to the equipment to be controlled, thereby making the need for separate control cables unnecessary.

In the 'Rhythmic' system \* signal differentiation is obtained by interrupting the audio frequency current at different rhythms. Twenty four different rhythms are utilised and transmitted at 485 Hz, this frequency being selected as most suitable with reference to the distribution network impedance.

11kV injection points are normally utilised, each transmitter unit consisting of a 3 phase motor driving a 485cps alternator which in turn feeds, via an isolator, an impulsing thyristor controlled by a solid state rhythm generator. The signal pulses are then fed, via an isolating transformer and series LC coupling elements, to the 11kV feeders as shown in Fig. ( 1.15 ).

\*Ripple Control System used by the Jersey Electricity Company Ltd for controlling approximately 15 MW of off-peak load.



**RIPPLE CONTROL TRANSMITTER**

Fig 1.15



The Ripple Control Receiver is illustrated in Fig. (1.16) and consists of a band-pass electrical filter which is tuned to 485 Hz and provides a low impedance path to the signal current and a high impedance to 50 Hz. The filtered signal is then rectified and applied to a pair of galvo<sup>†</sup> coils limiting the voltage to a maximum of 1 volt, therefore, any large transient voltages or surges on the network, even if at the correct frequency, will not activate the galvos. Each galvo unit is mechanically tuned to respond to one rhythm only, therefore, each switching relay has two distinct filters, one electrical and one mechanical; these ensure correct operation and give immunity from false operation.

The galvo units are extremely sensitive, each pair having a total resistance of 1250 ohms and will operate within 5 to 7 seconds on a 0.7 volt signal, leaving a margin of safety, the operating current at this voltage is 0.56 mA and the DC power required by the galvo for operation is 0.4 mW. As the galvos are pulsed by the signal current, the magnetic field produced by the coils causes the armature to swing and gradually increase in amplitude, until fixed contact on the frame, this completes the circuit for the operating coil of the latching relay which switches 'ON' or 'OFF' the main load carrying circuit.

#### 1.9.2

#### Cycle Marking Systems (Peak Depression)

In the late 1950s a novel system was devised that arranged discrete marking of selected cycles of the 50 Hz mains rather than modulating the mains with a unique signal frequency. A schematic of a single phase transmitter is shown in Fig (1.17) which 'marks' the 50 Hz mains voltage by applying a limited and precisely controlled short circuit. The pulse technique employed depresses the supply voltage for a few micro seconds by drawing heavy currents from the system at a precise preselected position on the voltage wave.

<sup>†</sup> galvonometer

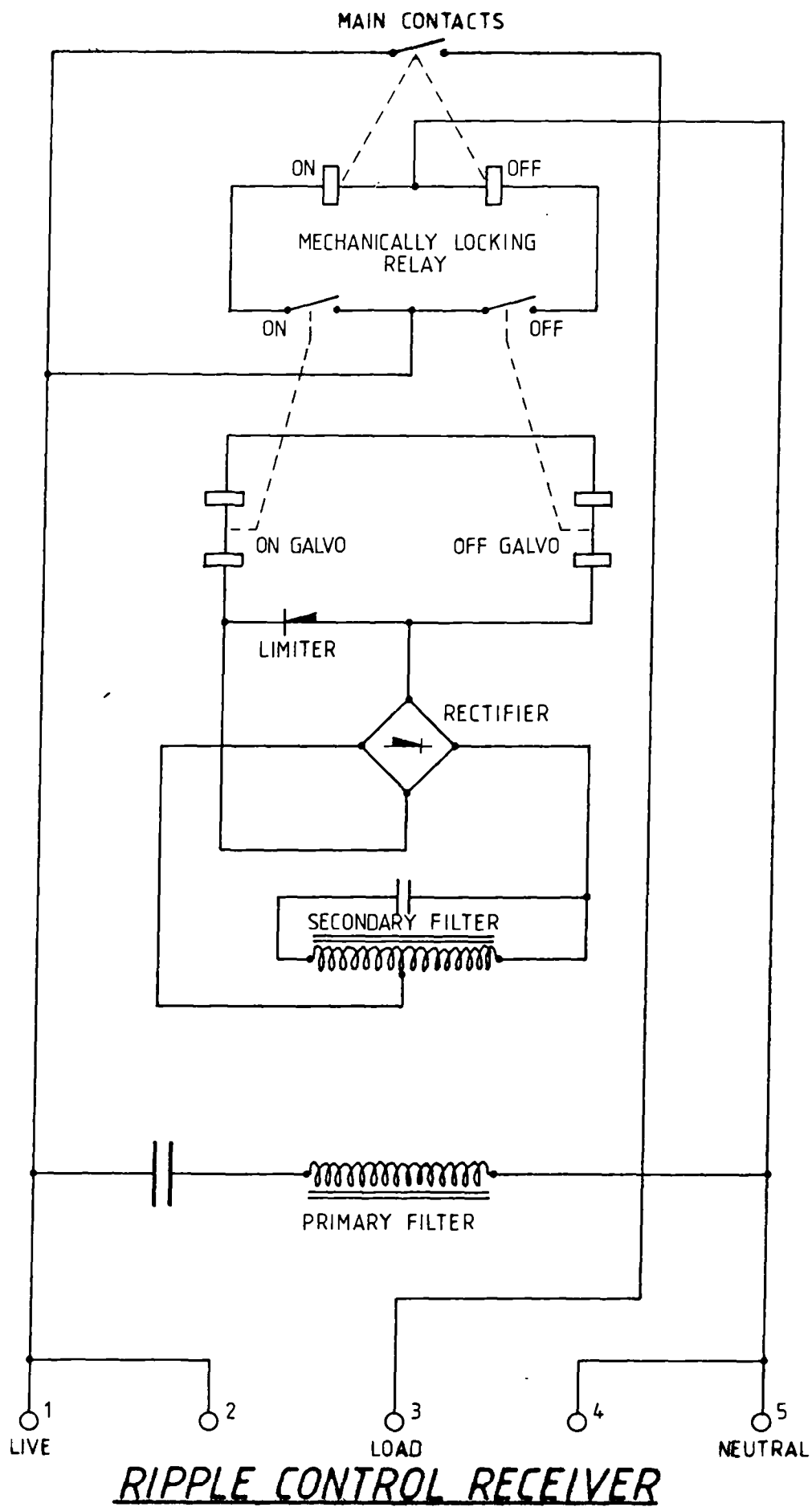
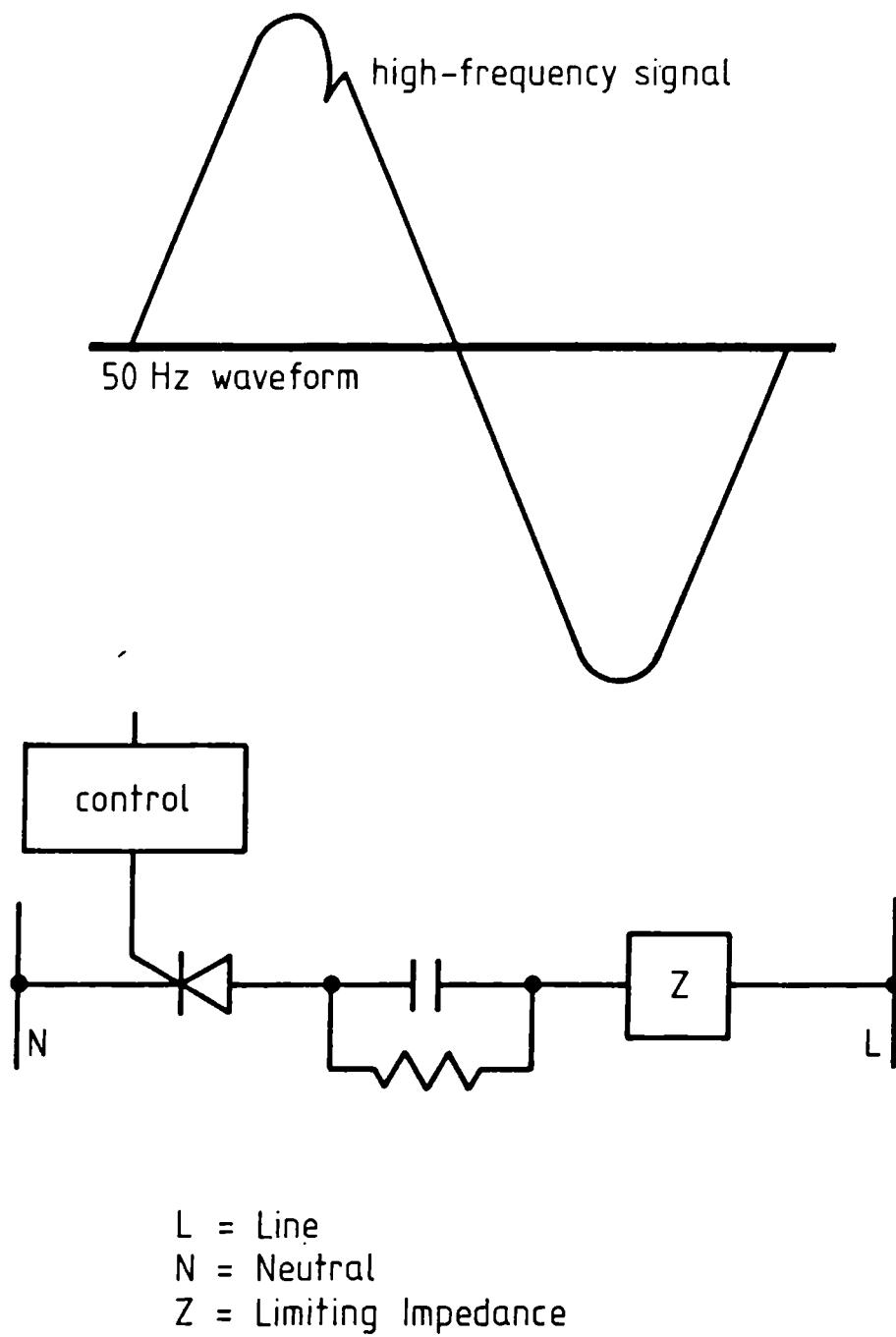


Fig 1.16



### FUNDAMENTAL SIGNAL GENERATOR

Fig 1.17

Early tests confirmed that the signals travelled long distances along unloaded or lightly loaded cables, while in densely loaded systems, signals travelled shorter distances and attenuation resulted from both cable loadings and interconnection with other supplies.

Further research by the London Electric Board and the GEC company led to the development of more sophisticated systems which utilised zone crossing point impression giving enhanced transmission characteristics over complex and heavily loaded distribution networks.

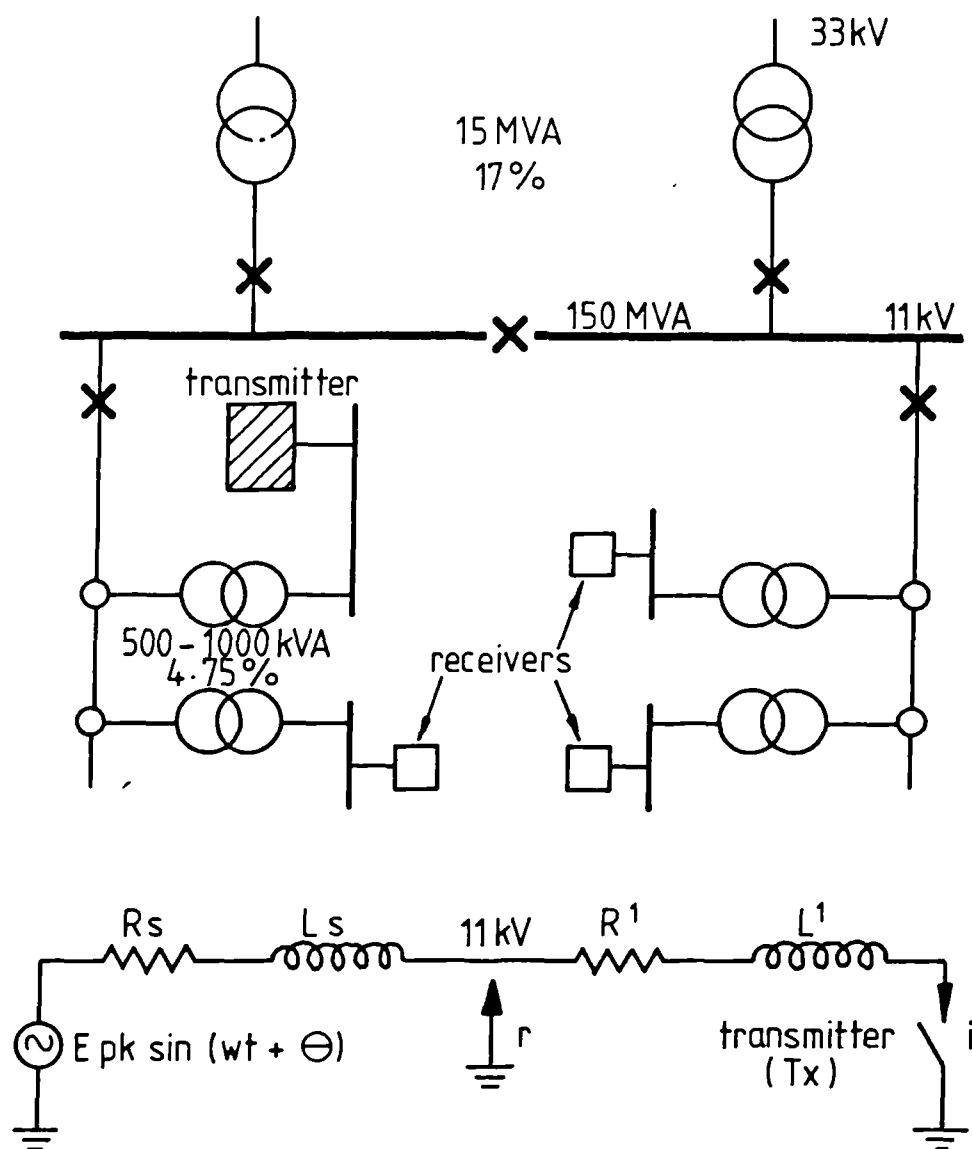
### 1.9.3

#### Cyclocontrol (Zero-Crossing)

The principal characteristics of this type of signalling are to produce distortions in the voltage waveform at a point on the low voltage network where maximum signal is produced with a minimum of disturbance to loads connected to the system. Voltage distortions causing at, or near to, the voltage peak may result in disturbance to loads, particularly to lighting and television loads, unless separately coupled from the low voltage to the high voltage system.

To avoid such separate coupling, it is possible to introduce a voltage distortion near to the zero-crossing point of the voltage wave. The distortion in the voltage waveform as in the peak depression systems can be produced by a sudden application of load. The lower the impedance of the load applied, the greater will be the distortion in the voltage waveform, thus the highest magnitude for the transmitted signal will be obtained when the impedance of the applied load is zero i.e. when a short circuit is applied to the power system, at the transmitter point.

A typical power system where this type of signalling method may be used is shown in Fig. (1.18), in which a simplified equivalent network diagram is included.



$R_s$  = SOURCE RESISTANCE

$R^1$  = RESISTANCE OF DISTRIBUTION TRANSFORMER, TRANSMITTER, 11kV & L.V. CABLE

$L_s$  = SOURCE INDUCTANCE

$L^1$  = INDUCTANCE OF DISTRIBUTION TRANSFORMER, TRANSMITTER, 11kV & L.V. CABLE

$i$  = TRANSMITTER CURRENT

### SIMPLIFIED NETWORK & EQUIVALENT CIRCUIT

Fig 1.18

When the transmitter signal  $i$  is applied, i.e. when the transmitter switch is closed, the transmitter current is given by the following equation:

$$i = \frac{E}{Z} [\sin (wt + \theta - \phi) - \sin (\theta - \phi) \exp (-\frac{RT}{L})]$$

Where  $\theta$  is the angle of the voltage wave at which the short circuit is applied,  $\phi$  is the angle of the system impedance =

$$\tan^{-1} \frac{w(L_s + L')(R_s + R')}{(R_s + R') + jw(L_s + L')}$$

and  $Z$  is the total system impedance =

$$(R_s + R') + jw(L_s + L')$$

Current and voltage waveforms at the transmitter point, and the receiver voltage when the signal is applied just before the voltage zero, are shown in Fig. (1.19). The currents and voltages shown in this diagram correspond to those found in a typical distribution network.

On switching the transmitter, the per unit voltage  $v$  appearing at the 11kV busbar is given by the expression:

$$V = \frac{Z'}{Z} [\sin (wt + \theta - \phi + \phi') - \frac{\sin (\phi - \phi') \sin (\theta - \phi)}{\sin \phi} \exp (-\frac{RT}{L})]$$

Where  $Z'$  is the impedance of the distribution transformer, including its 11kV cable and also the impedance of the low voltage cable plus transmitter and  $\phi$  is the phase angle of  $Z'$ .

In the receiver, the integral of the mains voltage waveform is measured during a fixed period (usually 0.8ms) after each positive going zero-crossing point. At the end of this period, the integral value is memorised and the integrator reset to zero. The amplitude of each integral is compared with that of the previous cycle in order to look for a preset difference that would indicate the presence of a signal. A typical example of a waveform distortion is shown in Fig. (1.19 ).

An equivalent network diagram for signalling over a typical distribution network is shown in Fig. (1.20). Table (1.12 ) shows comparative data for signalling via 500kVA, 750kVA and 1000kVA transformers. The impedances shown are referred to a base of 415v, as is impedance of a typical transmitter, i.e.  $1 \times 10^3$  ohms. Considering the series connected circuits and ignoring any shunt-connected impedances, the signal voltage appearing at any point P in the system can be calculated from the expression:

$$\text{percent signal} = 100 \times \frac{Z_s}{Z}$$

where  $Z_s$  is the impedance between the source E and the point P, and  $Z$  is the total impedance between the source E and the switch TX. The calculated signal voltages appearing at various points in the system are shown, and these must be multiplied by approximately 0.7 in order to obtain the practical values which actually occur. Using the 0.7 factor it can be seen, therefore, that when signalling via a 500kVA transformer the signal level appearing at the 11kV 150 MVA busbars will be approximately  $0.7 \times 6.2 = 4.3\%$ . The corresponding figures using 750kVA and 1000kVA transformers are 5.3% and 7.8%, respectively.

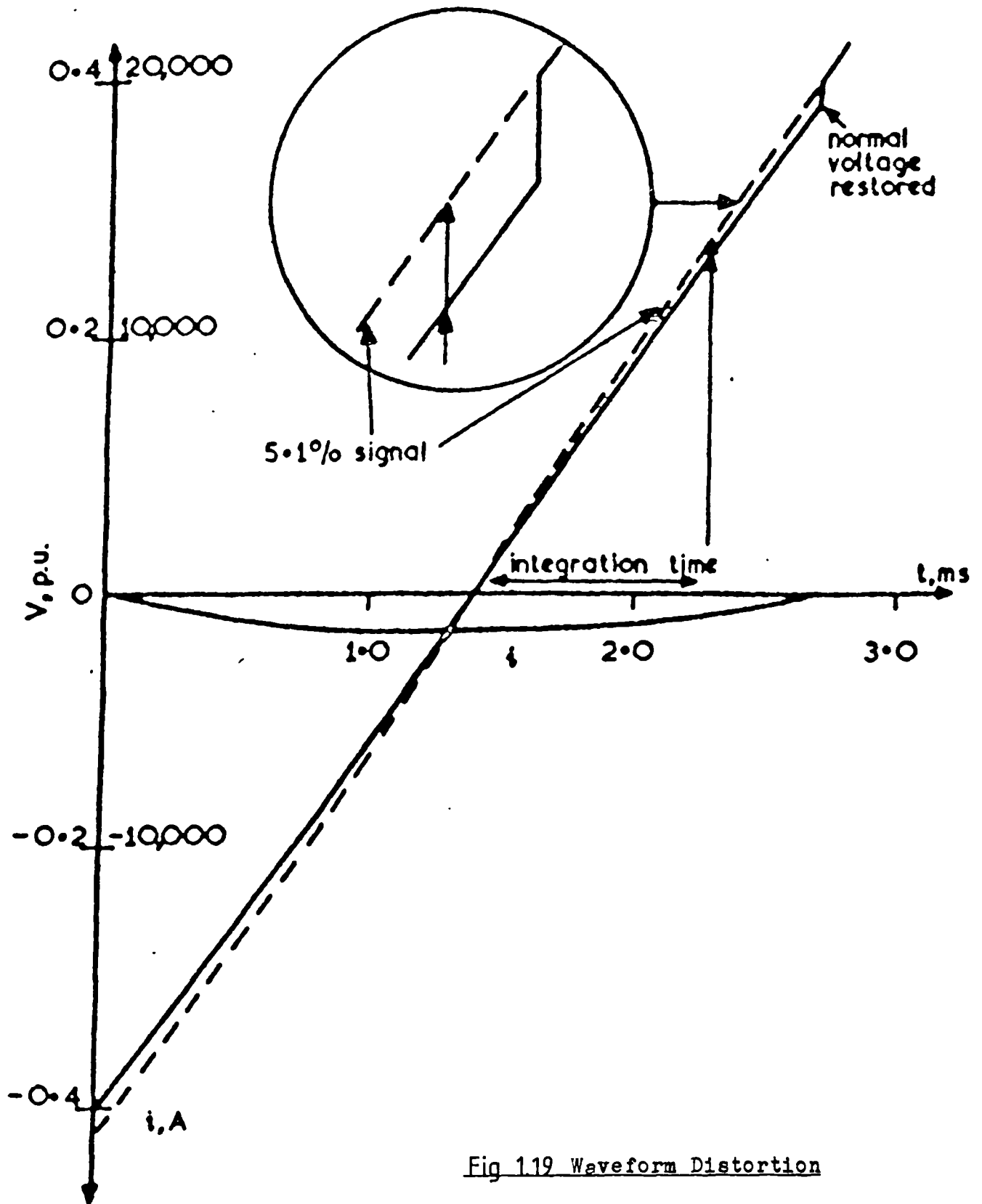
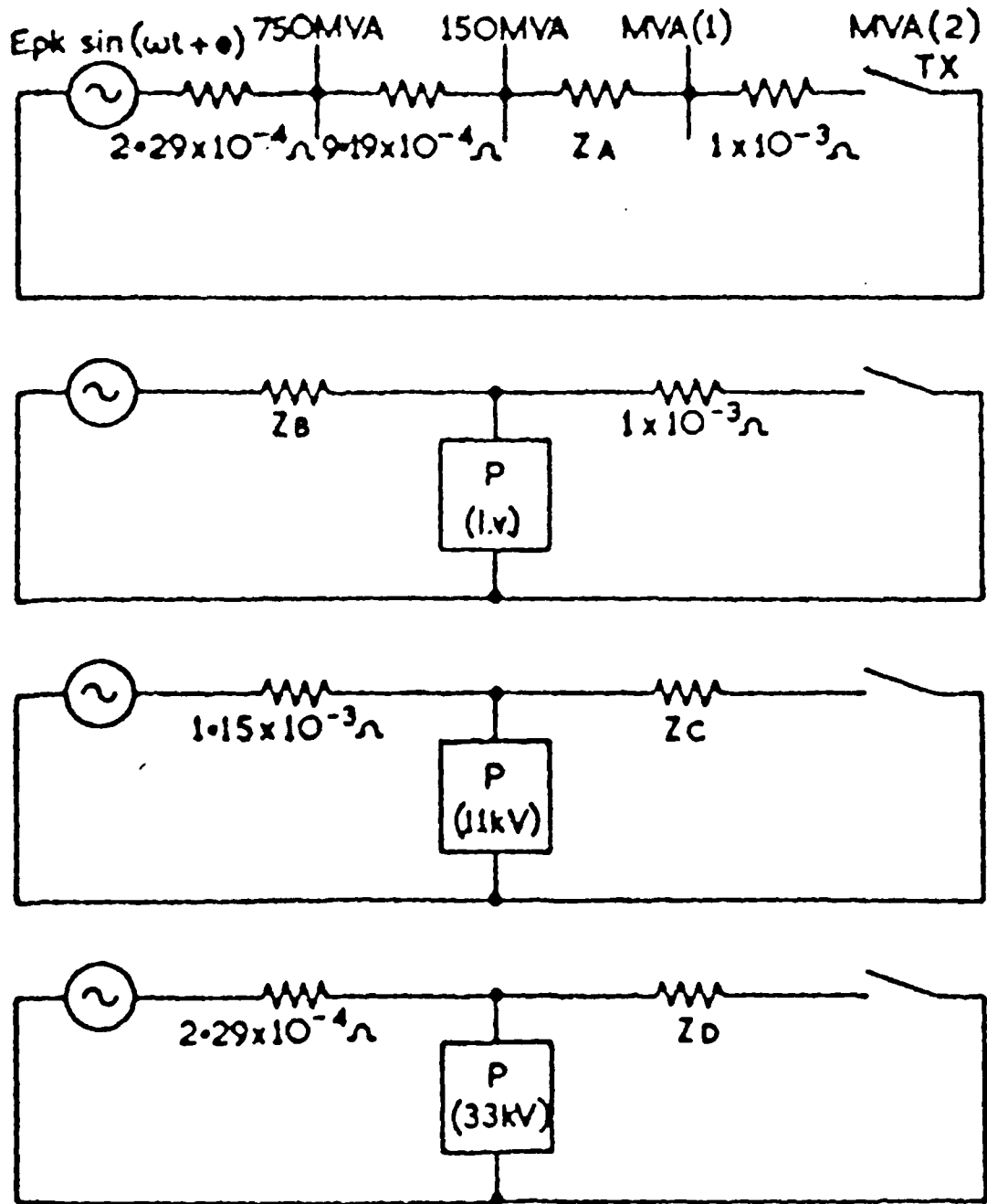


Fig 1.19 Waveform Distortion

*Signal voltage*

750 kVA transformer





*System equivalent network diagram*

500/750/1000 kVA transformer

Fig 1.20



Should the 11kV busbar fault level be raised to say, 200MVA, then the approximate signal levels would be 3.3% for a 500kVA transformer, 4.3% for a 750kVA transformer and 6% for a 1000kVA transformer. Results obtained from practical installations confirm that these simple calculations are a reasonable estimate of actual values.

To transmit a message a telegram, comprising a specified number of mains cycles, needs to be reshaped in a recognisable code pattern. The complexity of the code chosen depends on the signal/noise ratio of the signalling system, the degree of dependability and security required and the amount of information transmitted.

Simple codes are usually for load control applications thus enabling receiver costs to be minimised. The code arrangement selected, shown in Table (113), spans a period of 34 cycles of the mains supply and is transmitted on all three phases in sequence. A routing circuit in the transmitter connects the code generator to each phase in turn for a period of 40 cycles. After the three phases have been serviced, there is a waiting period of a further 40 cycles before the sequence is repeated.

Receivers are designed to reset immediately an incoming signal pattern differs from the present address; e.g. if a noise signal precedes a valid code transmission, the receiver will reset as soon as it detects an address error. The stop bit on cycle 34 at the end of the code greatly increases code security by eliminating the possibility of a false start bit causing the last information bit of a 5-bit code to be recognised mistakenly as a stop bit.

Cycle numbers													
1	2	3	4	5	6	7	8-19	20	21	22	23	24	
1	—	1	—	0	—	1	—	0	—	0	—	1	—
*start bit		3 out of 11 address bits											
		number of combinations = 165											
25	26	27	28	29	30	31	32	33	34				
0	—	0	—	1	—	0	—	0	1				
1 out of 4 instruction bits (see below )								stop bit					

Table T 1.3

## SELECTED CODE ARRANGEMENT

Function		Instruction							
Channel 1	Channel 2	25	27	29	31				
on	on	1	—	0	—	0	—	0	—
off	on	0	—	1	—	0	—	0	—
on	off	0	—	0	—	1	—	0	—
off	off	0	—	0	—	0	—	1	—

1.10Spread Spectrum Systems (Distribution Network)

(60)(61)(127)

A spread spectrum system is one in which the transmitted signal is spread over a much wider frequency band than that required to transmit the information sent. For example a voice channel would require only a few kilohertz but in a spread spectrum system this would be distributed over a band which might be several megahertz wide.

Spread spectrum systems have the advantage of permitting signalling through high noise levels and cope well with situations where the interference arises at varying frequencies. There are three general categories of system:

1. Direct sequence where a carrier is modulated by a digital code sequence whose bit rate is much higher than the information signal bandwidth. 0's and 1's of the message are each represented by distinct code sequence.
2. Frequency hoppers where the carrier frequency shifts in discrete increments in a pattern dictated by a code sequence.
3. Pulsed FM or "chirp" modulation where pulsed RF signals are used whose frequency varies in some known way during each pulse period.

The spread spectrum technique is particularly useful in the following areas:-

- a. Signalling through high noise or jamming; the wide frequency spectrum of the signal combined with a relatively low data rate permits signalling through a noise or jamming level many times that of the signal. Hence the technique is particularly suitable for signalling along the electricity mains.
- b. Low density power spectra for signal hiding; the signal is immersed in the noise.
- c. Sending of secure messages; detection and decoding of any message required knowledge of the code used to produce the signal.
- d. Code division multiplexing; the capacity of a communications bearer can be increased by the use of several different code formats. In this case it is essential to use codes with very low cross-correlation levels.
- e. High resolution ranging; this is an application of spread spectrum used for accurate positioning of space probes. The signal waveform is a function of time and comparison of the waveform at the receiver with that at the transmitter can be used to measure the distance of the probe from the receiving station.

Current prototype mainsborne systems employ the 'Direct Sequence' method. The data is spread over a much wider frequency band by using code frequencies of 1,024 bits to represent the 0's and 1's of the message. The clock frequency of the code sequence being 200 kHz.

The pulse pattern appears generally as shown below:-

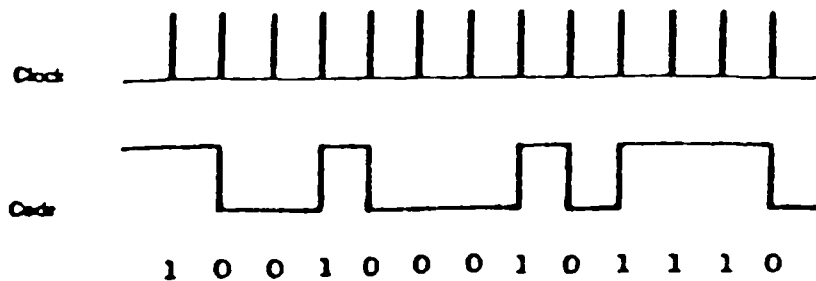


Fig 1.21 DIRECT SEQUENCE PULSE PATTERN

At the receiver the received pulse pattern is correlated with a reference. Precautions are taken to allow for the difference in synchronisation between the transmitter and receiver clocks.

Typically only part of the code sequence will be received as a result of interference during transmission. However the chosen code sequence is such that only a relatively small part of the sequence needs to be received for an 0 or 1 data bit to be output from the correlator. The correlation level is set so that the probability of erroneous detection of a data bit is acceptably low with any remaining errors being detected by checking the entire message.

In the frequency domain, the spread spectrum signal appears as shown overleaf. The frequency spectrum is produced by going through a mathematical transformation process (Fourier Transform) of the time domain pattern shown above.

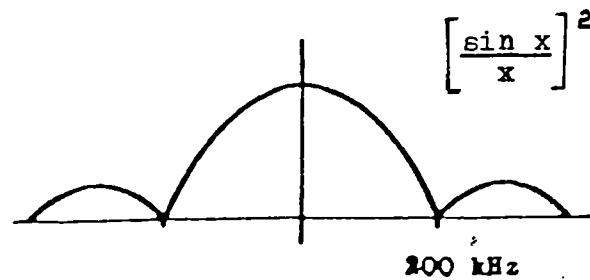


Fig 1.22 POWER AGAINST FREQUENCY FOR DIRECT SEQUENCE SIGNAL

The form of the power spectrum is  $(\sin x/x)^2$  with the first null occurring at the clock frequency. This is 200 kHz and coincides with the Radio 4 frequency thus avoiding interference in this band.

The selection of the code sequences is of greater importance. Maximal sequences are a convenient form of linear code because they can be readily produced using a shift-register sequence generator and have the desired correlation characteristics. In particular auto-correlation (comparing a code sequence with a phase shifted replica of itself) which is the process used to determine whether an 0 or 1 data bit has been received, is a two-valued function with a peak only at the zero shift point.

Low cross-correlation between different maximal sequences necessary to distinguish reliability between data 0's and data 1's can also be achieved by careful selection of the form of the sequence.

Currently mainsborne telecontrol is being evaluated in trials involving 1000 consumers on 5 different sites in London and Milton Keynes. The trial system is under development by Thorn EMI and utilises signalling along power lines in the 50kHz to 150 kHz band and provides bi-directional communication with the consumer.



It should be noted that Power Line Carrier, Ripple Control, Cycle Marking, Cyclocontrol and Spread Spectrum Signalling Techniques were each developed as a result of the available technology and with reference to the particular requirements of the system application. Historically there is little real overlap and it is beyond the scope of this thesis to attempt a comparison between these techniques.

## CHAPTER 2

### TELECOMMUNICATIONS SYSTEMS AND NETWORKS FOR CONSUMER ACCESS

#### 2.1

#### Introduction

The selection of the communication channel between the ESI and its consumers has a great influence for the overall economics of any remote metering system. The installation and commissioning of new systems is an expensive operation, although the materials themselves may be relatively cheap.

There are a number of grouping points which already exist at which it would be convenient to position remote meter reading and energy management telecommunications equipment. These are illustrated in Fig. (2.1) , together with some of the possible communication paths, and may be summarised as follows :-

1. The consumer's premises (i.e. on or about the metering unit)
2. A central point within a large block of dwellings. (i.e. Utility services area in basement etc.)
3. The local M.V. (Medium Voltage) transformer.
4. The local Telephone Company exchange building repeater or street cabinet.
5. The local UHF Television and or VHF,FM Radio broadcast site.
6. The local mobile radiotelephone base station site. (i.e. cellular radio).
7. The local Electricity Board Office or Depot.
8. ESI mobile radio telephone broadcast sites.

In the immediate environs of the meter, within the curtilage of the dwelling, there is only one usable communications path which is already connected to a meter i.e. the electricity supply mains. Any other telecommunications alternative requires to be interconnected to the meter via a suitable interface (e.g. the PSTN exchange line).

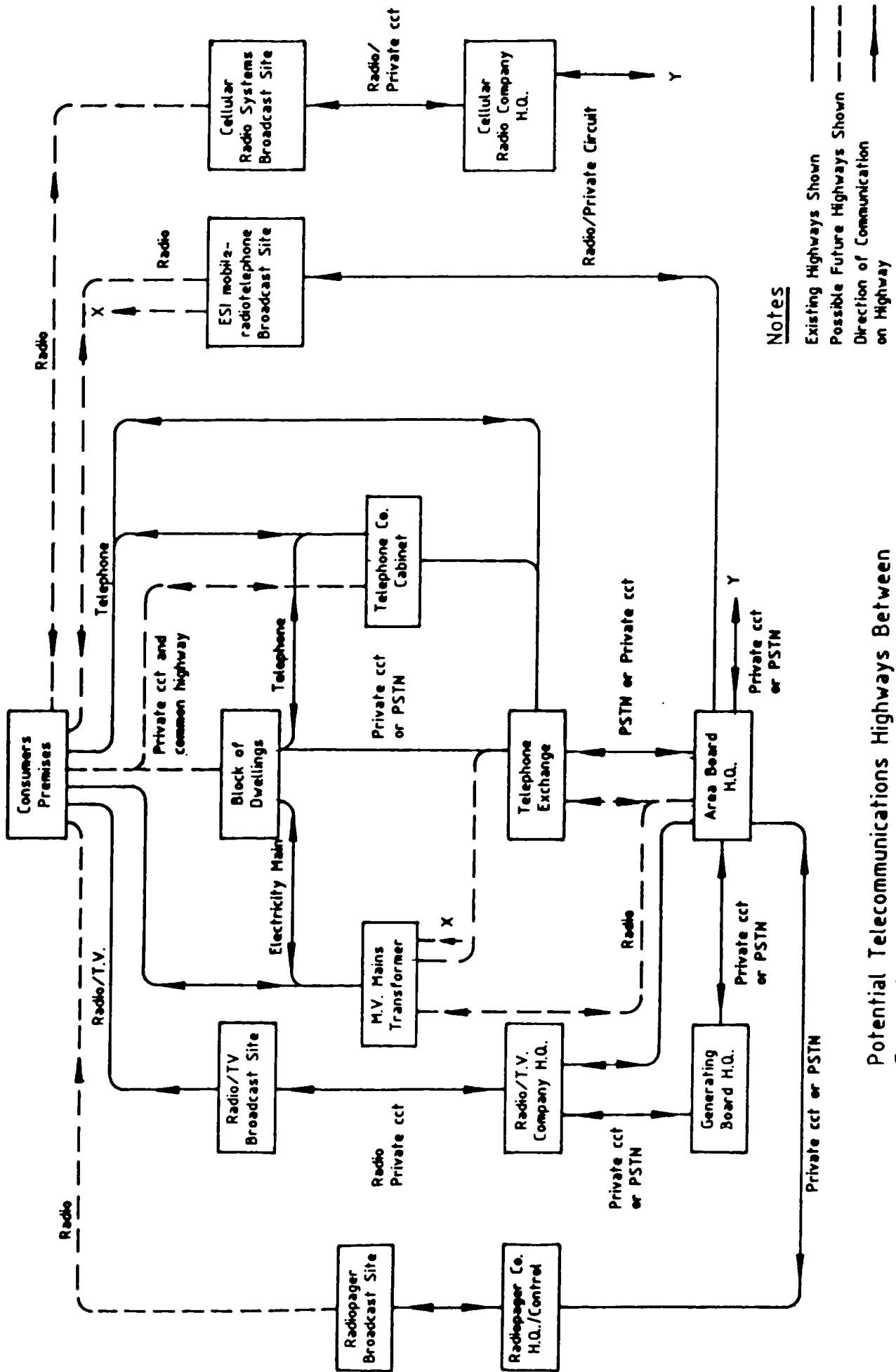


Fig 2.1

Potential Telecommunications Highways Between  
Generating/Area Board H.Q. and Consumer

Similarly interconnection of the external communication highway by any means, other than the electricity mains, will require a special interface.

63

Table (72.1) details the potential national telecommunications systems and networks which might be utilised for the purpose of remote metering and or load control. The service penetration, capability for additional data transmission and direction of communication (i.e. one on two way) is listed for reference.

## 2.2

### The mains electricity supply

Mains electricity is supplied to almost every dwelling and is, of course, connected to every electricity meter. It is therefore unique in the 100% penetration figure and its potential capability of providing a communications channel.

The mains electricity system is a common highway system, and consumers' meters must be separately identifiable if communication is to be established using this potential telecommunication link. Address identification equipment is therefore required at each electricity meter with no opportunity to spread the cost between a number of consumers. Also the mains system is inherently noisy and current experiments involving spread spectrum techniques indicate communication to the MV transformer is feasible. However at voltage levels above 440 volt a transfer to an alternative link becomes necessary (i.e rented private circuit, PSTN, PLC etc).

(114)

The coverage of each transformer averages 135 consumers. In rural areas, many consumers are supplied from pole-mounted transformers which only supply 4 consumers or so. There are some 154,000 free-standing transformers serving urban areas, and some 243,000 pole mounted transformers in the U.K. Therefore, if the mains is to be used for communications at the local level with the consumer, a very large number of communications interfaces will be required, each serving relatively few consumers, especially in rural areas.

SERVICE	PENETRATION %	CAPABILITY FOR ADDITIONAL DATA TRANSMISSION	DIRECTION	COMMENTS
Electricity Mains	100	Under Investigation	Bi-directional	Spread spectrum techniques currently under investigation.
Broadcast Radio (L.F. M.F. H.F. & V.H.F.)	100 (taken overall)	Good	Uni-directional	The majority of consumers own a domestic radio receiver.
Broadcast TV (U.H.F.)	95	Good	Uni-directional	The majority of consumers own a domestic UHF television receiver.
Telephone PSTN	85	Good	Bi-directional	Majority of domestic subscribers use telephone less than 20 mins. in each 24 hr. period.
Cellular mobile radiotelephone networks	95 (target)	Good	Bi-directional	Overnight the systems carry relatively little traffic.
ESI mobile radiotelephone networks	90 (estimated)	Good	Bi-directional	Overnight the systems carry relatively little traffic.
Wired Broadcast Networks	10	Good	Bi-directional	Low national penetration.
Radio-pager	95 (target)	Good	Uni-directional	Overnight the systems carry relatively little traffic.

Table T 2.1

The network averages 1.1 consumer interruptions per consumer a year, lasting 1.7 hours a year, of which 20% are pre-arranged.

### 2.3

#### The Private Switched Telephone Network (PSTN)

The PSTN could be utilised for communications purposes in many different ways :-

1. Via local exchange lines which already terminate on the consumers telephone instrument or systems (e.g. PABX). British Telecom have already begun to evaluate such a system 'Bit Stream' designed to meet a variety of telemetry needs associated with energy management and load control. The system utilises idle line working (i.e. the quiet period when the consumer is not actually engaged in a telephone call - the majority of the time :).
2. For the occasional transmission of bulk data between the Area Board HQ and the PSTN exchanges. A number of types of circuit already exist for such services and only standard equipment would be required to make use of them.
3. Consumers (or telephone subscribers) line plant usually consists of two pairs of wires from the dwelling to the street cable junction. Of these, only one pair is required for the telephone, and the other pair might well be made available for meter reading and or load control. Similarly in the local street cable, there may sometimes be spare pairs which could be used in common highway mode to the next node in the system.

The PSTN provides a bi-directional communications channel. Convenient points in the network at which to connect or interface with electrical equipment, for communications purposes, are the exterior of the dwelling adjacent to a line termination or entry point, the street cabinet and the telephone exchange.

The economics of such a system are tied to the coverage each of the interface points has in terms of numbers of consumers. On average, 83 subscribers are covered by a sheet cabinet and 3,250 subscribers are covered by each exchange. If lines are shared, the line plant cabinet catchment area would cover at least 270 electricity consumers and the exchange would cover 10,000 consumers. In rural areas, exchanges cover some 330 subscribers or 1000 electricity consumers.

(89)

The penetration figures for the PSTN are illustrated in Fig (2.2) and the regional variations may be noted. The failure rate of a local exchange line is approximately one failure in 6 years, and restoration takes on average 36 hours.

#### 2.4

##### Private circuit

A private circuit, in this context, is a telecommunications channel dedicated to remote meter reading and or local control. It may be uni-directional or bi-directional.

#### 2.5

##### Common highway

A common highway, in this context, is a telecommunications channel utilised for the transmission of more than one metering signal per unit-time. It may be uni-directional or bi-directional.

#### 2.6

##### Telecommunications interfaces or terminating equipment

Signals will be in digital form, enabling the use of micro-electronic equipment to give relatively cheap, effective and reliable transmission. The interface and or terminating equipment will probably be centred around solid-state large-scale or very large scale integrated circuits (LSI and VLSI).

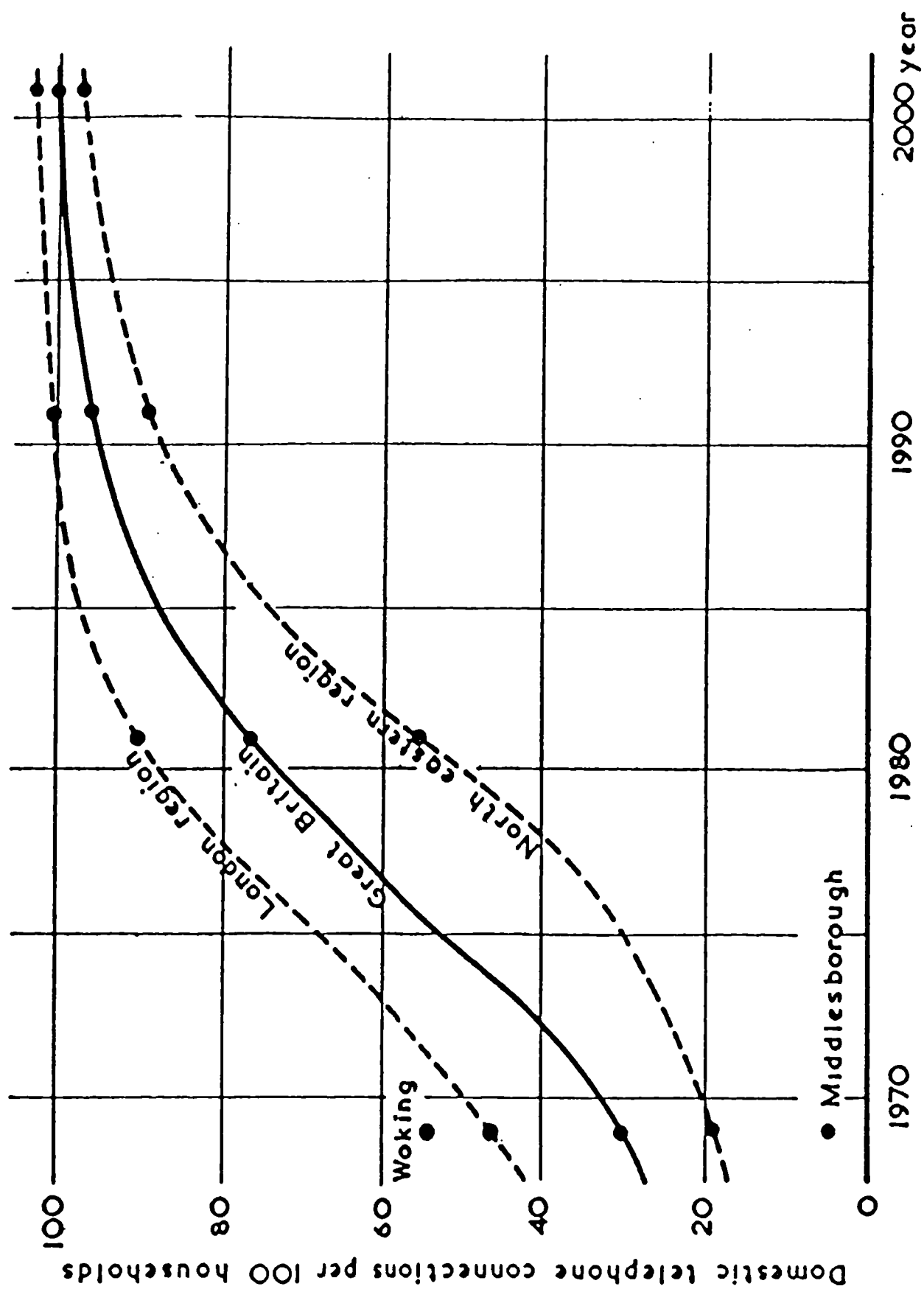


Fig 2.2

ESTIMATED FUTURE PENETRATION OF TELEPHONES.



## 2.7

### Broadcast Radio

L.F. and M.F., in this context, refers to Long and Medium waveband transmissions and such systems are uni-directional. The ESI in collaboration with the BBC have developed a technique for applying phase modulation to the BBC's long wave transmitters on 200kHz which is used for Radio 4 broadcast during the day and World Service during the early hours of the morning. With the application of modern analogue integrated circuits receiving devices are relatively cheap and national trials are underway to assess tariff switching via the system.

H.F and V.H.F. The H.F. spectrum (3 to 30MHz) is not particularly useful for relatively short range data transmission with complex modulation techniques and relatively expensive receiving equipment. However the VHF spectrum (30 to 300MHz) can be used with relative simplicity and combined with existing services. It is a uni-directional system.

## 2.8

### Broadcast Television

The U.H.F. 625 lines PAL standard is utilised in the U.K. and is a uni-directional system. Data transmission is already included in both BBC and IBA broadcasts. Most television receivers are now being equipped with electrical interfaces to cater for video recorders, home computer interfaces etc., and both composite video and audio may be input and output.

## 2.9

### Cellular Mobile Radio Telephones Networks

In the U.K., at the present time, there are two major cellular systems. The services commenced operation in 1985 and provide full voice telephony services to mobile users. The use of data over the systems is becoming increasingly important and a number of field trials have been undertaken with regard to data transmission over these systems. The systems are bi-directional and operate in the VHF and UHF spectrum.

2.10ESI Mobile Radio Telephone Networks

The ESI has a number of radio telephone networks provided to support the safe, efficient and economic distribution of electrical energy. The systems are bi-directional, operate in the VHF spectrum and give good coverage within the U.K. (NB the systems taken as a whole). The use of data over the systems is becoming increasingly important and a number of field trials are currently underway.

2.11Radiopager Networks

There are a number of radio pager networks in operation with the U.K. they are uni-directional and operate within the VHF spectrum. They transmit text via data burst and the display formats utilised are becoming more extensive and versatile (i.e. several words or lines of text may be transmitted).

2.12Wired Broadcasting Systems

It is estimated that current wired broadcasting systems penetrate fewer than (8)(9)(10) 10% of all households, and then only the denser urban areas. Although the (93) 'Cabling of Britain' has been much talked about little real progress has (111) been made with the exception of certain 'New Towns'. Existing wired systems tend to operate on a common highway basis and are generally uni-directional due to the distribution amplifier configuration utilised.

CURRENT METER READING AND CUSTOMER BILLING - AN OVERVIEW3.1  
Introduction

Metering enables charges to be related to consumption and is one way of discouraging waste and exercising a measure of control over demand. Electricity supplies are always metered and in the UK there are approximately 20 million electricity meters distributed among more than 18 million dwellings. In general these meters are read quarterly and this initiates the billing routine. Billing does not have to be coupled directly with a reading - estimated consumption can provide a satisfactory basis for billing. The cost of metering and billing varies with dwelling density, but the costs are evenly distributed between consumers and account for about 6 percent of the average domestic bill, while the reading function alone accounts for only about 0.85 percent. Prepayment meters are more popular in the UK than anywhere else in the world, accounting for 12 percent of electricity meters; they offer advantages to both the Area Board and consumer whenever long term credit arrangements are unsatisfactory.

3.2  
Present Meter Reading Methods

Meters are regularly read by 2,300 electricity meter readers in Britain and about one quarter of their time is spent in entering dwellings and one half in travelling. The average cost of meter reading alone is £0.29 a year per (89) consumer and costs are higher in rural areas and lower in high density urban areas. The cost of reading prepayment meters, which includes cash collection, (89) is £0.55 a year per consumer. It is worth remembering that electricity supplies have a universal penetration. There is some evidence that meter reading costs in the UK are lower than most developed countries, suggesting that motivation to change practice is higher in some other countries.

Analysis of existing meter reading practices suggests five main areas of potential economy:-

1. Increasing the meter readers' productivity.
2. Consumer assistance with reading.
3. Reducing the frequency of reading.
4. Rendering meters more accessible.
5. Fitting semi-automatic devices to meters to assist the reader.

Of all these, reduction in reading frequency would appear to offer the biggest savings, since annual reading would at least halve costs. The externally accessible meter boxes are now fitted by Area Boards where practical and particularly in new housing developments. Increases in productivity do not offer substantial gains and self reading systems which are reliant on the consumer have not been successful. Semi-automatic devices which relay the reading to a central grouping point are not economic, but could find some application where admittance is a major problem.

3.4Billing Systems

(89)

Credit billing proves costly £0.09 per transaction (£0.36 a year for quarterly billing), largely because between one-fifth and one-third of all consumers requires a reminder to pay (issued 28 days after the first bill) and the average delay in payment is 18 days. The present optimum economic period between bills is some 110 days, representing the balance between interest charges and billing and reading costs. This period is little influenced by meter reading costs even if the meter reading costs were zero, the ideal billing period would only reduce to 80 days. It is concluded, therefore, that at present quarterly billing is acceptable regardless of reading practice. Budget accounts offer significant savings in billing costs, they need only one meter reading a year and if all large consumers were on budget accounts and small consumers were only read and billed once a year, the savings would increase further. Prepayment meters have a longer optimum cycle of 116 days for urban electricity, but the overall collection costs are much higher than credit billing costs, as there are comparatively few prepayment meters in use.

3.5Attitudes of Consumers and Utilities

Little investigation of consumer attitudes has been carried out by utilities and there has been little apparent consumer interest. Credit meters are favoured, but pre-payment meters are seen to offer benefits to itinerant consumers and those who find budgeting difficult. Credit consumers find quarterly reading and billing convenient, but would not object to increased use of estimated readings and budget accounts are liked by their holders. There is some evidence that consumers are virtually indifferent to the methods of billing or meter reading and remote reading as performed by the telephone services excites little criticism. To the utilities, meter reading is only a subsidiary function, but this has not precluded experiment including self read cards, change of frequency, estimated readings and budget accounts. In general it appears that external meters are favoured and prepayment meters are accepted. Utilities will not change their metering practice without clear economic advantage to themselves.

3.6Legal aspects and Accuracy and Reliability of Metering Systems

Apparatus for metering must be approved, but there are few other legal constraints on methods of metering electricity and none which preclude metering or the registration of consumption remote from the consumer. Only the gas utility is required to provide prepayment meters on demand. Accuracy and reliability are not specified to much depth and the accuracy of the present overall systems rest on the meter, but its reliability depends on the reader as well. Net error rates are estimated to be about one per quarter to half a million readings. All utilities have checking and validating procedures for cases of complaint. To date, 1990, British Telecom and Mercury Communications have a virtual duopoly over telecommunications services within the UK.

## CHAPTER 4

### REMOTE METER READING CONCEPTS

#### 4.1

#### Introduction

In the design of a remote metering system it is necessary to consider the tasks that are carried out by the meter reader.

At each house he takes a meter reading, or several if there is more than one meter, and checks the setting of any tariff time switches. The meters are usually fixed inside a meter cabinet or on a meter board, together with the supply cable termination and the fuses. In reading the meter a simple visual examination covers many important aspects of safety and security. <sup>(81)(82)</sup>

If the consumer is worried about his installation the meter reader provides a first point of contact, and the subject can be raised. The behaviour of the consumer can often indicate that something is wrong, and this can be important, particularly with senior citizens who might be reluctant to make complaint.

It is relatively easy to read a meter automatically, but more difficult to <sup>(109)</sup> replace the meter reader.

The cost of reading a meter is very difficult to estimate accurately, and varies from house to house and from district to district. One estimate suggests the cost (1983) as £2.00 per meter per year. If we accept this as a sensible figure it is worth comparing it with the cost of remote reading equipment.

A unit that consumes 5W will use more than £2.00 of electricity per year, and therefore power consumption is critical.

A unit that requires servicing or replacing every 10 years may cost at least £20.00 a service visit, and so eliminate the suggested saving.

The meter reader provides very good value for money. If costs were the only consideration the same meter reader could read both electricity and gas meters. To justify remote meter reading we must look for additional savings.

#### 4.2 Practical Methods

Many methods have been proposed for the remote reading of meters, varying widely in both cost and capability:-

1. Remote meters
2. Optical scanning
3. Radio interrogation
4. Telephone telemetry
5. Cable TV
6. Mains-borne systems
7. Management schemes

#### 4.2.1

##### Remote Meters

In some countries, such as Canada, it can be difficult to reach houses in the winter, and meters are often external, perhaps by the nearest road, to make meter reading easier as shown in Fig (4.1). In some urban areas groups of meters for all three utilities are placed side by side to reduce reading problems as shown in Fig. (4.2). This method is very simple and practical, but could not be used in an area where vandalism is prevalent - particularly as the meters plug in, and are relatively easy to remove.

#### 4.2.2

##### Optical Scanning

Where meters are sited by the roadside they can be fitted with dials marked using optical bar codes so that automatic readings can be carried out from a passing vehicle. This has been used in Canada at speeds of about 50/kM/hour.

#### 4.2.3

##### Radio Interrogation

(53)

In the USA the PURDAX system for remote metering used radio interrogation to read meters from a passing van. The use of 960 MHz transmissions excited passive resonant loops in the meters, which responded at the second-harmonic frequency of 1.92 GHz using diode rectification. The system is no longer used for metering but is in volume production for shop security.



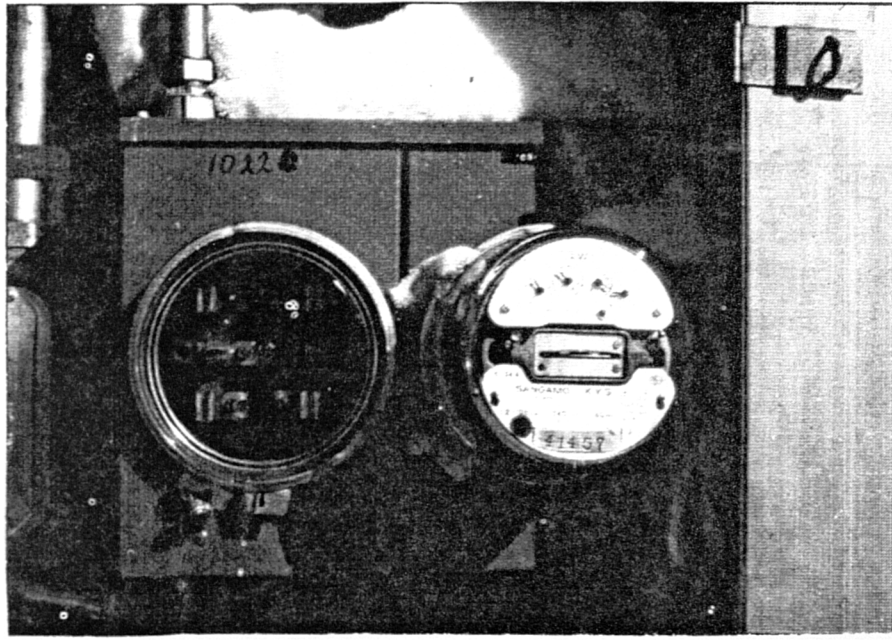


Fig 4.1

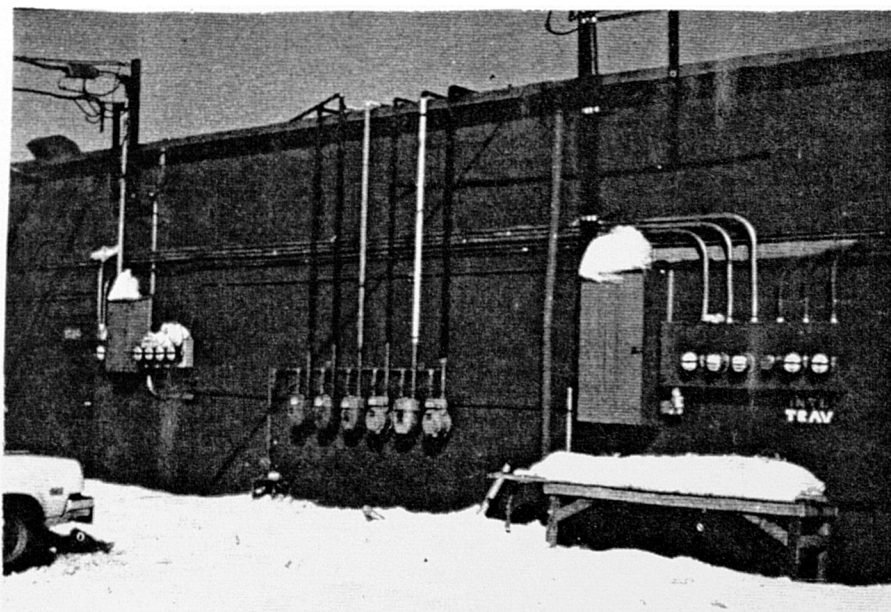


Fig 4.2

(84)  
In the UK the radio teleswitch trials are using subaudio phase modulation of the BBC Radio 4 carrier wave for load control, where the cost justification is provided by load control. Similar work in California uses the public broadcast system to address meters which radiate their readings on a 200 MHz carrier.

#### 4.2.4

#### Telephone Interrogation

The South Eastern Electricity Board uses its credit and load management scheme (CALMS) <sup>(83)</sup> for both load control and remote metering. The scheme provides a sound long-term approach. It should be noted that a number of simpler schemes in the USA have failed as the charges for use of the telephone link were increased. The need for a favourable agreement with British Telecom is essential for this scheme, which can provide a wide range of facilities for both the supply industry and the consumer. At the present time published proposals indicate 40 telephone calls a day by the supply industry (1983) compared with four by the average subscriber, which in the USA has been the factor that made changes for use of the telephone system higher than could be justified.

#### 4.2.5

#### Cable TV

(8)(9)(10)(93)  
In the proposals published for cable TV remote metering is quoted as a future application. Here the allocation of costs is even more critical than with the telephone.

4.2.6Mains-borne Systems

In the UK a scheme sponsored by the Department of Industry is investigating  
(111)  
load control and remote metering using the mains itself as a communication  
path. The total bandwidth available on the distribution network is  
10-150 KHz, and the trials taking place in London and Milton Keynes use  
(127)  
spread-spectrum signalling in the band 50-150 KHz. Early results that have  
been published show transmission problems in the evenings that are probably  
caused by TV interference.

Other mains-borne schemes achieve 400m range, and provide an excellent basis  
for City Centre use.

Where a house is well separated from its neighbours and the range is  
insufficient another scheme should be used.

The range restriction appears to be due to constantly varying loads on the  
network together with the following:-

1. High interference (noise) levels on the network
2. Transmission nulls
3. Radio signals
4. Other users

Transmission nulls occur where the transmission lines (power lines) involved  
extend beyond a quarter wavelength of the frequencies utilised. Also if  
equivalent circuit analysis were to be undertaken on sections of the  
distribution network natural filter networks can be found which give rise to  
transmission nulls.

Mains-borne systems are, however, increasingly being used for short-distance transmission, for instance within their houses and factories, and an initial code of practice has been published by TACMA. (330)

#### 4.2.7 Management Schemes

New energy-management schemes are continuously being developed. In the USA, in one year alone, the following schemes were started, most of which included prototype metering:-

1. 32 radio systems (mostly load control only)
2. 11 ripple systems (load control only)
3. 3 mains-borne systems
4. 13 hybrid systems
5. 2 telephone based systems.

Current trends in the USA are toward radio load control schemes, without remote metering.

#### 4.3 Reliability and Metering

Any metering system has to be extremely reliable; customers seldom complain if a meter fails - provided their bills decrease. They do, however, object strongly to excessive bills.

Present day meters cost a few tens of pounds and run for 20 years with negligible failures, and so provide a challenging standard. (331)

A remote metering scheme has to achieve comparable reliability and be cost justified - a difficult task for electronics. If a remote meter disagrees with the consumer's meter the resulting dispute may be very expensive, and so the preferred solution is that the remote system must read the registers of the consumer's meter - which is only feasible with electronic meters.

A major step towards remote metering was the development of the solid-state meter. The first of which was detailed at the IEE meter conference in October 1982, but a cost effective electronic register is still needed before it can be practically incorporated into remote metering.

#### 4.4 Towards Remote Metering

The ESI is continuously seeking methods for using fuel more efficiently, to provide better service without increased costs. The solid state meter provides the possibility of registering multiple tariffs at a small increase in cost that could not be achieved with electro mechanical devices.

A communication system is necessary to control a multiple-tariff meter if the consumer is to receive maximum benefit.

Communication paths are being developed which enable the supply industry to offer multiple tariffs. The radio path already exists, and others are rapidly under development, some of which offer 2-way communication.

Where a solid-state meter is fitted with a solid-state register and connected to a communication path, remote metering can be provided at substantially zero cost. There is a real possibility of present developments reaching this state in relatively few years from now.

## CHAPTER 5

### ESI - CONSUMER BILLING INTERFACE

#### 5.1

#### Introduction

The subject of current meter reading and customer billing procedures has already been covered in Chapter 3. Here a typical Area Board system for the meter reading - billing process is analysed.

This chapter seeks to investigate the major areas which may be more cost effectively served by the utilisation of Telecommunications and Computer based systems.

Consider the basic meter reading - billing process as illustrated in Fig (5.1)

The system relies to a great extent on the following :-

##### 5.1.1

An Adequate Road Transport System. The meter reader has to travel from premises to premises. Securicor has to travel with the metering sheets to the Computer Centre. The bills or accounts have to be sent via Royal Mail which again requires road transportation and the customer has to pay his/her account similarly or by a visit to the Utility premises (e.g. a showroom).

This suggests that the transportation component is much less for high density areas of population where the journeys will be much shorter compared with those in the sparsely populated rural areas where a high travelling overhead is incurred.

# **BASIC METER READING-BILLING PROCESS**

83

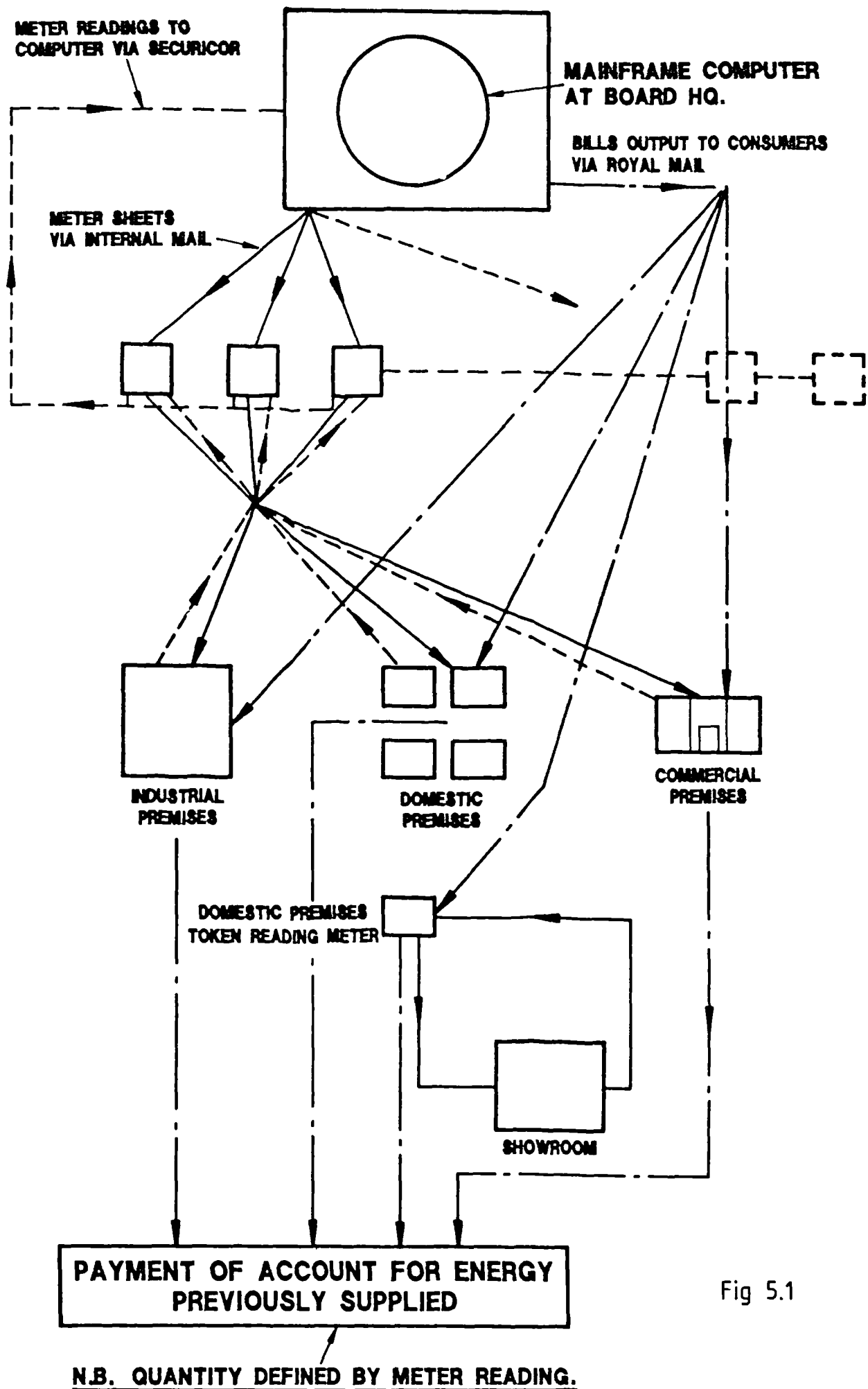


Fig 5.1



5.1.2

Easy Access to the Meter. This is not usually a problem with industrial premises (which are most frequently visited - once per month for large consumers) but domestic and commercial premises do present a problem and outside meter cabinets are currently utilised in modern premises to overcome this problem.

5.1.3

An Effective Accounting Process. This provides for the conversion of the meter reading into a sum of money which covers the Area Board charge for the amount of energy consumed since the previous meter reading. It may be time-of-day, type of supply (i.e. single or polyphase low, medium or high voltage), type of consumer (i.e. industrial, commercial or domestic) or a mixture of these factors upon which the actual tariff depends. The basic algorithm is however quite simple :-

- a)  $(\text{current meter reading} - \text{previous meter reading}) = \text{units consumed since last bill.}$
- b) Account number gives search key to tariff applicable.
- c)  $\text{Current bill for energy consumed} = (\text{charge per unit (tariff)} \times \text{units consumed}) + \text{any fixed charge.}$
- d) VAT is not currently charged.
- e) Account number gives search key to customers address etc.

- f) Print bill and insert into envelope.
- g) Mail to consumer.
- h) If consumer pays account within 'defined-period' (go to k).
- i) Customer has not paid account send a reminder or final demand.
- j) If no payment received within prescribed period prepare to take action such as cut-off-supply etc (go to cut-off supply routine).
- k) Update consumers computer records as account paid.

N.B. The above is normally a 'Batch Processing' routine on the mainframe computer with on-line access to customer accounts information. Typical print-outs from Customer Accounts on-line systems are illustrated in Table (T 5.1)

#### 5.1.4

Good Consumer Relations Meter readers must know how to deal effectively with the members of the public which they regularly meet bearing in mind that they may be the only personal contact that the consumer has with the Utility. They must know the basic source of advice for a consumer with problems ranging from account queries to faulty appliances, especially if the appliances have also been purchased from the Utilities commercial outlets (i.e. showrooms). They must also be tactful when dealing with customers who have problems in paying their

## Typical Customer Account Print-outs

PAGE 1 OF 2

ACK A03:612781496926 UN FX4X AI 14271177/900711

A#61 27814 969 26 3 FX4X

902 39 39

00000000 00000000 00000000 01011111 280576 051 0000

00000000 00000000 00000000 00000000 00000000 00000000 00000000

0000 0001 0000 0000 0000

80 3

B\*MR P A BROWN

4 30 APPLERIGG

6 KENDOL CUMENLO L09 6L0

H\*1605 B3 1705 50 1705 FC 3105 C1 3107 B1 1108 FB 1708 C1

0211 B3 0811 FC 1511 C1 0202 B3 0802 FC 1602 F4 2102 F4

2602 C1 2802 C1 2802 C1 0203 CF 1005 B1 2205 FB 1206 C1

K\*013 8.83

F 0000000 0000000 0000700 50.81

M 10914 5 0 101 1 0 210375 41

7409 L 74 11 Q N N C

R 12 045431 220590 700

44 044731 190290 51

43 044680 150290 112

12 044568 060290 820

12 043748 081189 720

12 043028 110889 620

12 042408 170539 760

04 041648 060289 813

43 040839 151188 114

12 040721 111138 620

04 040101 190888 681

04 039420 170538

PAGE 2 OF 2

MR P A BROWN

902 80 39 220590

904 NEXT VISIT

Table T 5.1

accounts or who have, in the past, been 'cut-off' supply for non-payment etc. They should be sufficiently technically aware to notice signs of any meter tampering and or devices connected illegally for the purpose of fraud (i.e. obtaining electricity without due payment).

Telecommunications systems could certainly help to cut costs in areas 1 and 2 above but it is doubtful if communication via an electronic medium can replace effectively that personal face to face contact with the domestic consumer. It certainly cannot provide for examination of the meter against fault, damage or fraud without extensive investment (i.e. video system).

It is assumed that the actual capital cost of the necessary software and hardware to permit such interface between an electronic meter and a telecommunications network may be offset by other facilities provided by such a system. Indeed it is intended to show that the savings occurred from the utilisation of a central micro computer on a '24 hour' basis in both the 'stand-alone-dedicated-task' and 'real-time-control-mode' can permit optimum use of many, otherwise redundant, resources and that taken overall a good cost benefit is indicated.

(95) (112)

The 'intelligent home' philosophy is analysed in chapter 8 (see Fig 8.1) and it can be shown that home energy management including the generation of accounts, can be easily undertaken on the 'home micro-computer' thus removing the need for customer account generation on the Area Board or Utility mainframe computer. If the Utility computer resources were then directed at 'communications' with

the remote home microcomputers and with the electricity generating stations much enhanced energy management concepts may then become possible. Such systems would, of course, rely heavily on a reliable national telecommunications infrastructure for their efficient operation.

## CHAPTER 6

### LOAD CONTROL

#### 6.1

#### Introduction

Electricity charges (tariffs) have been the subject of extensive studies<sup>(87)</sup> both in terms of academic literature and more recently by experimentation ranging from localised case studies to widespread application. A recent example of this in the UK has been the development of a 'Radio Teleswitching System' undertaken jointly by the ESI and the BBC. The system is described more fully in chapter 7. It is sufficient here, to say that it is a method of load control which is based on data modulated on to the radio frequency carrier wave of a national radio station operating on a frequency of 200 kHz and, via special radio receivers interfaced to the consumers electricity metering system, permits a tariff change (and a consequent load increase or decrease) to be initiated as and when considered appropriate.

Electricity charges, or to be more precise schedules (tariffs), in which rates change periodically have become the subject of increasing debate<sup>(88)</sup> throughout the world. The argument generally put forward is that different rates per kilowatt hour should be charged during different pre-specified periods of the day, week and year. Such tariffs are generally referred to as time of day rates, and are currently being used in the UK originally via time switched meters and more recently by "Radio teleswitches" as briefly described above.

6.2Spot Pricing Theory

In order to analyse the philosophy of the time-of-day tariff the following approach is adopted:-

Assuming that different profiles of electricity use and investment overtime lead to different social welfare levels. Then a global social welfare function may be defined :-

$$\begin{array}{rcl}
 \text{Welfare} & = & \begin{array}{cc} \text{(1)} & \text{(2)} \\ \text{Value of Electricity} & - \text{Variable and Fuel} \\ \text{Usage} & \text{Costs} \end{array} \\
 & & \begin{array}{cc} \text{(3)} & \text{(4)} \\ - \text{Cost of Rationing} & - \text{Cost of Equipment} \end{array} \quad - - - - 6.1
 \end{array}$$

Terms 1 and 2 in Eq. 6.1 (Value of usage and fuel costs) may be treated as random variables, as they depend on random plant and network outages, weather, customer requirements, national - international financial factors, etc. The cost of rationing would tend to zero if the cost of the commodity (electricity) could be varied according to its true 'optimal' price at any given time. This situation may tend to become a practical one if reaction time can approach real time (ie with minimum response time for the real time distributed computer control system and an adequate national telecommunication infrastructure).

Then assuming a global controller, the decision variables become the generation level of each generating unit (power station), and the load requirements of each consumer, at each point in time. The aim is then to maximise the global social welfare function and by utilising the calculus of variations the conditions on which the decision variables are satisfied can be established.

Two basic constraints are imposed on this process:

#### Energy Balance

ie Total Generation = Total Consumption + System Losses      - - - - 6.2

---

#### Network

ie Voltage magnitude and line flow restrictions      - - - - 6.3

---

As the above relate to a composite electricity generation, transmission and distribution network they must also, by implication, involve the random variables of weather and outages together with the decision variables of generation and demand at each point in the network.

It can be shown that the constrained optimisation conditions are satisfied by optimal spot pricing in conjunction with standard economic despatching. That is to say if true spot prices are set each consumer will reach the socially optimal usage level as a result of its own efforts to maximise profit (ie effectively minimise energy expenditure)



The spot prices thus obtained are explicit functions of all the random variables and therefore vary as the random variables (ie with respect to time).

The formulas may be defined generally as follows:-

Optimum		Energy	T&D	
Spot	=	Marginal	+ Balance	+ Network - - - - 6.4
Price		Fuel Cost	Quality	Quality
			of Supply	of Supply
			Premium	Premium

---

NB. It follows that there are separate spot prices for real and reactive energy. (NB T&D = Transmission and Distribution ref 6.4 above)

Assuming that if spot pricing were to be implemented with a telecommunications network which was subject to blocking at times of peak traffic and or throughput delay then not all participants will be able to receive real time updates of the spot price.

In such a case the price at any given time  $t$  cannot reflect the actual values of random variables at time  $t_0$  but instead should be based on the projected or expected values of those random variables. Then the optimal predetermined price for time  $t$  is given by:

Optimal		Expected	
Predetermined	=	Value of	+ Covariance - - - - 6.5
Price		Optimal Spot	Term
		Price	

---

NB. The covariance term depends on the consumers demand behaviour and its correlation to the spot price. Also eq.6.5 and the theory developed, does not explicitly consider the cost of communicating the spot price to consumers and metering their usage.

As a finite time is required to communicate the spot prices to the consumer a more realistic approach is to implement a range of charges or tariffs.

- (a) Five minute spot price. This price is updated every five minutes based on all available information about demand and availability generator for capacity. If we ignore the T&D system, the correct 5 minute spot price is simply the marginal cost of another kWh from the least efficient generating unit on line. Therefore the price is set according to equation 6.4. For optimisation it is assumed that any associated communications network has a propagation delay of much less than 5 minutes.
- (b) Twenty four hour update spot price. This price varies each hour, according to a predetermined pattern updated once a day. This price is set according to equation 6.5 calculating the expected value of the spot prices based on all information available at the time of calculation. On most systems it will closely track the actual value of the optimal (5 minute) spot price. This system is an intermediate between full spot pricing and fully predetermined prices.
- (c) Time-of-Use price. This is a price pattern which is updated at long intervals, perhaps as rarely as once a year. On most systems there would be several prices per day, with charges at predetermined times of day. This price is set according to eq 6.5 calculating the expected value of spot price based on information available at the time of each update (eg beginning of the financial year).

Calculating the magnitude of the tariff (price) for each level can be done using existing mathematical models and computer based algorithms, since the different tariffs are analagous to existing problems in generation despatch. Five minute spot pricing is analagous to economic despatch, and the price is responsive to random weather variations, unexpected plant outages, and T&D failures. Twenty four hour update spot pricing is analagous to unit commitment, and reflects known outages and the daily weather forecast. Time-of-Use predetermined price is analagous to maintenance scheduling and nuclear unit refueling, and can reflect only the normal pattern of demand.

The only major new development needed to properly calculate each of these prices in real time is the development of a short-term demand response model. Such a model can be developed from experience as spot pricing is gradually implemented by a utility. If we ignore losses and the T&D system, all customers on one pricing system see the same price. This simplifies calculations.

Metering and Communications. Once the spot price has been determined it must be communicated to the consumers. The 5 minute spot price requires psuedo real-time-on-line communication via a suitable one-to-many broadcast system to advise users of the price updates. It follows that the 5 minute spot price must therefore carry the greatest communication overheads. The system response time for optimum usage is very short (ie much less than 5 minutes).

The 24 hour update spot price may be published in a daily newspaper or recorded on a telephone number which customers can call or be updated daily on a national information source. The communications overheads for this system are therefore reduced as is the necessary response time for optimum usage of such a system.

The time-of-use predetermined price is identical to the current practices for time-of-use rates. A switchable rate meter is the only hardware required. Regular bill inserts may be used to remind customers of next month's prices. No rapid response is required to optimise the usage of this pricing system.

### 6.3

Deciding the appropriate price (tariff). Consumers require to be assigned different tariffs depending upon their size and ability to respond to the more sophisticated pricing systems. The metering and communication costs will depend to a large extent on the price system chosen not on the consumer.

It follows that the cost of even 5-minute spot pricing will be trivial for large industrial or commercial consumers. Small residential domestic consumers whose demands are too small to justify the cost of a recording meter should be on time-of-use predetermined tariffs. Other consumers should probably be assigned a 24 hour update tariff or perhaps some hybrid between the tariffs. It should be noted that whilst the 5 minute spot price requires real time communication between the utility and the consumers the calculation of the account could take place on the customers premises assuming the computing resources were available or by recording demand during each interval (ie every hour or every 5 minutes, as appropriate). Other customers should probably be on the 24 hour update spot price tariffs. Another possibility would be to allow consumers to self-select their pricing, or overall tariff structure, provided that they meet all the incremental metering and communications costs incurred.

For the purposes of this report the problems of Losses and Reactive Energy and Quality of Supply are not detailed as their effects are primarily upon the spot price calculations rather than on the associated telecommunications system developed philosophy.

6.3.1

Rationing, however is relevant for if the consumer response to an increase in the spot price is insufficient to avoid a problem then there will be a requirement to shed load. This situation may also arise, for example, on systems where only a few customers are on 5-minute spot price tariffs. Such rationing or rotational load shedding may well have influence on the overall communications requirements for a spot pricing system.

6.4

Initial Implementation. Optimal spot pricing can be implemented for a few customers at a time. The social benefits of implementation are larger for those customers which are the most responsive to spot prices (in absolute MWh of demand shifted). This suggests starting with very large customers as 5-minute spot pricing requires sophisticated communication and metering. One hour spot pricing or 24 hour update pricing can easily be undertaken using existing technology.

It should be noted that customers paying optimal spot prices are always paying the full costs their demand imposes on the system. Therefore other customers cannot complain of discrimination in favour of spot price customers, especially if they too are offered the opportunity to pay optimal spot prices.

Different consumers would be on different levels of pricing sophistication (tariff) depending on their size and characteristics for example:-

Tariff 1

5-minute spot pricing

Separate prices for real and reactive energy

Individual adjustments for losses. T&D quality of supply.

Real-time communication with utility for prices.

Tariff 2

24-hour update spot pricing.

One price for real and reactive energy, but not necessarily the same weighting for each consumer.

Different adjustments for losses, T&D quality of supply by distribution feeder voltage.

Newspapers and radio used to communicate next day's prices.

Tariff 3

Time-of-use prices. Updated every one to twelve months, by bill inserts.

Two to three price periods each day.

Real time energy only; reactive energy ignored.

Losses and quality of supply adjustments equal for all customers in a region.

In general, larger consumers will be on more sophisticated price levels but ability to respond will also be a factor. Hence tariff 1 pricing might be appropriate for special types of customers in the near future. If the cost of electricity continues to rise while the cost of micro-electronics falls, the number of customers at more sophisticated tariffs will increase.

6.5

Practical Implementation may be undertaken on a gradual basis, with groups of consumers so that the power system evolves naturally from its present state into a composite spot pricing energy market place.

It follows that the natural starting place is with large industrial and commercial consumers which already have sophisticated energy controls in place. In the domestic residential sector, spot pricing may start with new homes and it is this area that is investigated in detail in chapter 8. The project also aims to highlight the potential for de-regulated electricity transmission and distribution companies to provide, and further develop, composite regional telecommunications networks and thereby provide a wide range of cost effective energy management services for their customers (consumers).